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A new Traffic Light Assessment for northern shrimp (*Pandalus borealis*) on the eastern Scotian Shelf

Nouvelle évaluation du stock de crevette nordique *(Pandalus borealis)* de l'est de la plate-forme Scotian selon la méthode des feux de circulation

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ABSTRACT

The DFO-industry survey index decreased in 2001 for the second consecutive year. The strong 1994 and 1995 year classes were nearly at the end of their life cycle in 2001 and recruitment to the fishery may be below average for the next 2 years, consequently the population appears to be declining from the historic high levels of the late 1990s. Environmental indicators, including temperatures and capelin abundance, appear to be unfavourable - increasing aggregation of shrimp on the grounds may be a response to these changing environmental conditions. Spawning stock biomass remains high, and the area with the lowest exploitation rate is experiencing declines similar to the more heavily fished areas, consequently the declines appear to be due more to environmental than fishing effects. However, increases in female exploitation, fewer larger females in the population due to removals by the fishery, increased fishing during the ovigerous period and decreases in the size at transition and maximum sizes may be impacting negatively on the population's reproductive capacity. The Traffic Light analysis for the eastern Scotian Shelf shrimp stock was revised and upgraded by extending the historical time series of many indicators to include the period of low abundances in the 1980s. The wider range of values during favourable and unfavourable conditions allowed the setting of definable and consistent (albeit arbitray) limits for the colours of individual indicators (0.66, 0.33 percentiles). The summary for both 2000 and 2001 was red, indicating a more severe intervention than the previous year. A population model was used to simulate a shrimp population subjected to the combined effects of fishing and unfavourable environmental conditions and the level of intervention needed to prevent the spawning stock biomass from decreasing below the lowest levels observed historically.

RÉSUMÉ

L'indice du relevé MPO-industrie en 2001 était à la baisse pour une deuxième année consécutive. En 2001, les fortes classes d'âge de 1994 et de 1995 approchaient de la fin de leur cycle vital; le recrutement pourrait être inférieur à la moyenne au cours des deux prochaines années, et il semble que la population diminue à la suite des niveaux records atteints à la fin des années 1990. Les indicateurs environnementaux, notamment la température et l'abondance du capelan, semblent défavorables; le regroupement croissant des crevettes sur les lieux de pêche constitue peut-être une réaction à ces modifications des conditions du milieu. La biomasse du stock reproducteur reste élevée; comme on observe des déclins semblables dans le secteur au taux d'exploitation le plus faible et dans les secteurs intensément pêchés, ces déclins seraient attribuables à des effets environnementaux plutôt qu'aux impacts de la pêche. Toutefois, la capacité de reproduction de la population pourrait souffrir de l'exploitation accrue des femelles et de la réduction du nombre de femelles de grande taille qui en résulte, de l'effort de pêche accru durant la période ovigère et des réductions de la taille au moment de la transition et de la taille maximale. Nous avons révisé l'analyse du stock de crevette de l'est de la plate-forme Scotian par la méthode des feux de circulation en allongeant la série chronologique de nombreux indicateurs pour inclure la période de faible abondance des années 1980. La gamme élargie de valeurs observées pendant des conditions favorables ou défavorables nous a permis d'établir des limites définissables et cohérentes (bien qu'arbitraires) pour les couleurs des divers indicateurs, soit les 33^{e} et 66^{e} centiles. Le résumé des indicateurs pour les années 2000 et 2001 a donné dans le rouge, ce qui indique qu'il faudra prendre des mesures plus strictes que l'an dernier. Nous nous sommes servis d'un modèle de population pour simuler les effets combinés de la pêche et de conditions du milieu défavorables sur une population de crevettes ainsi que le niveau d'intervention nécessaire pour empêcher la biomasse du stock reproducteur de baisser sous les planchers historiques.

INTRODUCTION

The biology of northern shrimp, *Pandalus borealis*, is reviewed in Shumway *et al.* (1985) for various stocks world-wide, and by Koeller et al (1996a) and Koeller (2000) for the eastern Scotian Shelf stock. The history of the eastern Scotian Shelf shrimp fishery and recent stock assessments are given in Koeller et al (1996b, 1996d, 1997,1998, 1999 and 2001). Although there has been some shrimp fishing on the Scotian Shelf since the 1960s the Nova Scotia fishery began to expand toward its full potential only when groundfish bycatch restrictions were overcome with the introduction of the Nordmore grate in 1991. The Total Allowable Catch (TAC) has been caught every year since individual Shrimp Fishing Areas (SFAs) quotas were lifted in 1994. With biomass at historical highs and continued good recruitment, the TAC was raised from 3100mt to 3600mt for 1997 and to 3800mt for 1998. There has been evidence of reduced recruitment in recent years, but because of continued high spawning stock biomasses, and large year classes (1994, 1995) recruiting to the fishery, the TAC was increased to 5000mt for 1999 and to 5500mt for 2000. With the 1995 year class completing its life cycle, recruitment only average, a decrease in the survey biomass, an increasing exploitation rate, changes in the distribution of the resource possibly due to increasing temperatures or other factors, and increasing harvest levels during the ovigerous period, the TAC was reduced to 5000 mt for 2001.

In 2001 shrimp prices dropped sharply due to large quantities of small shrimp in the Newfoundland and Labrador inshore fishery. This resulted in voluntary closures of the Newfoundland, Gulf of St. Lawrence and eastern Scotian Shelf fisheries during the summer. On the Scotian Shelf only one vessel continued to fish after the voluntary closure in early July because it freezes shrimp onboard and sells to a different market than the peeling plants which receive the bulk of the shrimp caught in the northwest Atlantic.

Beginning in 1999 the Newfoundland-Labrador, Gulf of St. Lawrence and Scotian Shelf shrimp stocks were assessed using the Traffic Light method of summarizing stock assessment results which was developed during several meetings of the Scientific Council of the North Atlantic Fisheries Organization (NAFO MS 1998, Koeller et al 2000). On the Scotian Shelf, a simple set of rules linking traffic light results to management action was also proposed (Koeller et al 1999), based on modelling results indicating that this would be more precautionary than the status quo (Koeller et al 2000). Although the Traffic Light approach has proved useful and was generally accepted by managers and industry, it has been criticised by the scientific community for lacking scientific rigor. This problem was addressed by the Fisheries Management Studies Working Group (FMSWG) of the Department of Fisheries and Ocean's Regional Advisory Process (Maritimes Region) beginning in 2000. Among the advances made by this group is the production of a computer program which summarises traffic light colours determined by pre-defined limits for individual indicators (Mohn et al 2001). In addition to an overall summary the program produces summaries for groups of indicators or "characteristics" such as biomass, production or fishing mortality. While the FMSWG has addressed other outstanding issues associated with the traffic light method, specifically, integration of the individual indicator scores including weighting of indicators, and linking traffic light results to harvest control rules, it has not resolved them to date.

In this report we use the Traffic Light program developed by the FMSWG to provide a more rigorous assessment of the eastern Scotian Shelf shrimp stock. In addition, we have extended many of the indicator time series as far back as possible to provide a wider range of observations for setting limits between lights. Despite these improvements, when results suggest that there should be a change in the TAC from the previous year, managers will still ask 'how much?' In order to provide more than an arbitrary answer to this question we conducted simulations with a stock model having characteristics similar to the Scotian Shelf shrimp stock. Because the Scotian Shelf shrimp stock is currently at a high level of abundance and a decrease is apparently underway, we asked the question 'approximately what level of intervention would be necessary to prevent or delay a stock decrease below a reference level due to a combination of fishing and environmental influences?'.

The organisation of this report is based on the traffic light analysis itself, with methods and results for individual indicators grouped under headings representing "characteristics", in the order they are presented in the summary. The sections on each indicator in Methods and Materials provide the methods used to calculate the indicators, and describe their relevance to the characteristic they represent. In Results and Discussion, the indicators always represent summary data for the entire area, i.e. all SFAs combined, according to the current practice of managing the fishery as one stock. The indicator series used in the analysis is given as an uncaptioned figure directly after the indicator heading. In addition to the indicator time series themselves, their sections in Results and Discussion include data which support trends seen in the summarized data. These data are given as numbered and captioned figures and tables at the end of the document. For example, individual SFA data often replicate the indicator trends and thus substantiate them. Supporting data may be entirely different from the main indicator, for example, catch rates in the shrimp trap fishery are given to support the apparent increasing shrimp aggregation shown by the survey and CPUE data. Although this additional information may be used in the interpretation associated with any change that is given in the Results and Discussion, it is not used in the summary Traffic Light scoring.

The shrimp fishing areas on the Scotian Shelf are shown in Figure 1. Table 1 provides basic catch statistics for the fishery since 1980 and Table 2 gives licencing information for the recent period covered under sharing agreements between the Scotia Fundy and Gulf fleets and an Integrated Management Plan which includes provisions for temporary licences during favourable periods. Note that from 1995-1998 the experimental trap fishery was not under quota management except for a 500 mt precautionary 'cap', and so the total catch exceeded the TAC due to the trap fishery catch. When the trap fishery in Chedebucto Bay was made permanent in 1998 a trap quota was set at 10% of the total TAC e.g. 500 tons of the 5000 mt TAC was initially allocated to trappers in 1998. Any uncaught portion of the initial trap quota was reallocated to the mobile fleet. This reallocation has tended to be late in the year and some fishers were unable to take advantage of the additional quota, hence the catch has been slightly lower than the TAC since 1998.

METHODS AND MATERIALS

Traffic light Indicators

Default boundaries between traffic lights for individual indicators i.e. transition from green to yellow and from yellow to red were taken as the 0.66 and 0.33 percentiles, respectively, of the data in the series unless an increase was considered bad for stock health, in which case these were reversed. In two cases it was apparent that the polarity of the default boundary was inappropriate when considered in conjunction with other indicators for certain years. Clearly, the increase in the two commercial CPUE series, coupled with increased aggregation and decreased survey abundance, indicated that the increase in the two commercial CPUE series in the most recent years should now be viewed as a negative development as a precaution. However, traffic lights were not changed from the default, as this was not supported by the RAP peer review committee.

ABUNDANCE

Research Vessel Abundance Index

A sixth industry funded trawl survey, incorporating a mixed stratified random - fixed station design, was conducted in June 2001. Survey design and station selection methods were similar to previous surveys completed in 1995-2000: fishing depths >100 fathoms, randomly selected stations in strata 13 and 15; fixed stations in strata 14 due to the difficulty in finding trawlable bottom; 30 minute tow length; 2.5 knot vessel speed. Stations in Strata 17 (inshore) were selected randomly at all depths having a bottom type identified as La Have clay on Atlantic Geosciences Centre surficial geology maps. The 2001 survey was completed by MV *Carmel V* fishing the standard survey trawl (Gourock #1126 2-bridle shrimp trawl and #9 Bison doors). Measurements of trawl wing spread and headline height were made throughout all survey sets using SCANMAR sensors.

Catches were standardised to the target distance travelled at 2.5 knots for 30 min (1.25 nm). Biomass/population estimates and bootstrapped confidence intervals (Smith 1997) were calculated using the product of the average measured wing spread (17.4 m) of the survey trawl and the distance travelled during a standard survey set (1.25nm) as the standard unit area swept by each set (Halliday and Koeller 1981).

The co-operative DFO-industry series begun in 1995 used several different vessel-trawl combinations requiring comparative fishing experiments in 1996 and 1997 (Koeller et al 1997). In order to obtain a wider range of indicator values for this series it was extended to include DFO surveys conducted in 1982-88, a period of low abundance in contrast to the present period of high abundance. There were no comparative fishing experiments which allowed direct intercalibration of the two survey series, consequently catch data were only adjusted by the difference in the wing spreads of the trawls used. Wing spreads were based on the performance specifications of the trawl used for the earlier series, and from actual measurements for the latter series. Since the cod end mesh size in both series was the same (40 mm) size selectivities of the two series were assumed to be the same.

Gulf Vessels Catch Per Unit Effort

A CPUE index for Gulf based vessels, which have the longest history in the fishery, is calculated as a simple unstandardised mean catch/hour fished for all vessels fishing in any given year. These are the largest vessels in the fleet and although the participating vessels have changed considerably, they have always been >65 ft in length, compared to the <65ft Nova Scotia fleet. This is considered an important time series because it spans periods of both high and low abundance of the stock.

Commercial trawler Standardized Catch Per Unit Effort

The standardised CPUE series for 1993-2001 uses data from April-July inclusive, the months when the majority of the TAC was caught, for vessels that have fished for at least 4 of the 9 yr series. A multiple regression analysis was conducted with year, month, area and vessel as categorical components. Predicted values and confidence limits for a reference vessel, month and area were then calculated for each year according to Gavaris (1980). Data on catch rates were obtained from fishers' logs required from all participants and provided by DFO Maritimes Region Statistics Branch.

An increase in this and the previous indicator does not necessarily indicate increasing stock abundance, especially when coupled with a decrease in the area fished (see commercial fishing area below) or a decrease in the dispersion of the stock (see research vessel coefficient of variation below).

Research Vessel Coefficient of Variation

A measure of dispersion was calculated from survey data as the simple coefficients of variation of all survey sets for each year i.e. the standard deviation of all catches divided by the overall average weight caught. An increase in this statistic indicates increased aggregation of shrimp on the grounds.

Commercial fishing area

A measure of dispersion was also calculated from commercial data as the number of area units (1 minute square rectangles) having an average catch of >250kg per hour. With catch rates continuing to increase but survey estimates decreasing, a decrease in this index would indicate a concentration of the remaining stock in smaller areas.

Industry perspective

In 1995, 2000 and 2001 a questionnaire was used to facilitate input of information from the fishing industry on various aspects of the fishery and the resource (Appendix 1). Vessel captains were interviewed by telephone at the end of the fishing season. Questionnaire results were not used as indicators in the Traffic Light analysis but are presented in support of the interpretation of specific indicators.

PRODUCTION

Commercial counts

Data on the count per pound by vessels landing in Canso, N.S. were collected by the main shrimp buyer in the area (Seafreeze Ltd.) who uses this information to determine landed value to fishers based on a pre-arranged pricing scale. Counts from each vessel's landings were made by taking a random sample of shrimp from 10 separate bags from each fishing day. An annual average count was calculated from all daily counts from all vessels.

This indicator is a measure of the ease or difficulty fishers are having in "making the count" i.e. getting the best price for their shrimp. An increase in the count could indicate that a) recruitment is good and there are so many small shrimp it is difficult to avoid them or b) the population of larger shrimp is declining, or a combination of a) and b). Consequently this indicator must be considered with others including abundance indices of the different age categories. Counts change considerably during the fishing season, usually starting relatively high, decreasing to a minimum in July, and increasing thereafter.

RV Age 2 abundance

A random sample of 10 pounds of shrimp (approximately 500 individuals) was collected from the catch of each survey set and frozen for detailed analysis, i.e. carapace length, individual weight, sex and egg developmental stage. Survey population estimates (numbers) were determined by the swept area method using individual set length frequencies and weights caught, and a length-weight relationship. Survey population estimates by age group were then estimated by separating total population at length estimates from the swept area method into inferred age groups using modal analysis (MIX, MacDonald and Pitcher 1979).

The Age 2 abundance indicator is currently the only estimate of recruitment to the population. However, these shrimp are not caught efficiently by the standard survey trawl and research is being conducted on improving early recruitment estimates using a beam trawl during special juvenile surveys and by placing small-meshed bags on the standard survey trawl during the regular June survey.

RV Age 4 abundance

Age 4 abundance is calculated as per Age 2 above, from survey population at length estimates (swept area) and modal analysis.

On the Scotian Shelf most Age 4 shrimp are in their final year as males. This group represents shrimp that will breed during the survey year and will change sex the following year. They also comprise the bulk of the catch for the next year, and so are a measure of recruitment to the fishery.

RV spawning stock biomass (Females)

The spawning stock biomass (SSB), or total weight of females in the population was calculated with the swept area method from the weight of females in each set, determined by identifying females and their lengths in the detailed sample, the total catch weight, and a length weight relationship. This estimate includes shrimp that were in the transition stage during the survey. On the Scotian Shelf transitional shrimp are seldom found during the fall i.e. all transitionals complete sex change during the summer and extrude eggs during the late summer and fall.

A stock recruitment relationship has not been identified for the Scotian Shelf, although it has been for some other pandalid stocks, e.g. the Gulf of Maine, California-Oregon. On the Scotian Shelf a large population increase began during the late 1980s when SSBs were about 4,300mt, about 30% of those found in the late 1990s. It would therefor be prudent not to let the SSB decrease below 4,300, however, the stock increase at these SSB levels ocurred at specific favourable environmental conditions and negligible fishing mortalities. Consequently, this SSB should be considered as the very lowest the stock should be allowed to decline. It is nearly identical to the default 0.33 percentile used as the red limit for most indicators, including SSB.

SSB by itself is not a measure of reproductive capacity. Since fecundity is directly related to size, it should be considered in conjunction with the average size at sex transition, maximum size and amount of fishing during the ovigerous period.

Average size at sex transition (L_t)

Shrimp in transition from the male to the female are identified by the pleopod development method and their average size is calculated as an overall weighted average from all sets in the survey.

A decrease in size at transition has often been associated with a population decline, although the mechanism behind this has been unclear. Koeller et al (in press) show that size at transition is related to growth rate. An increase in growth rate, due to density dependant effects or temperature increases (Koeller et al 2000), results in decreases in the size at transition, maximum size and fecundity, followed by a population decline.

Average maximum size (L_{max})

Average annual maximum size is calculated as the average of the sample maximum sizes.

The ratio of size at sex transition to maximum size was hypothsised to be constant (invariant) at about 0.8-0.9 for all stocks of *P. borealis* (Charnov and Skulladotir 2000). This rule was shown to apply to the Scotian Shelf (Koeller et al., in press). Therefor maximum size attained in the population is another measure of growth rate, however, because maximum potential size appears to be set at the time of sex transition L_{max} is probably more indicative of growth several years previously.

Predation

A predation index is calculated as the mean catch/set for all groundfish species from the summer groundfish survey for strata which encompass the shrimp holes i.e. 443-445 and 459.

This is considered an index of natural mortality. Groundfish abundance is negatively correllated with shrimp abundance on th4e Scotian Shelf and in most other shrimp fishing areas.

RV bottom temperatures

This index is calculated from July groundfish survey data as the mean bottom temperatures at depths >100 m on the eastern Scotian Shelf. Temperatures were recorded with expendable bathythermographs (XBTs) or reversing thermometers. Beginning in 1995 near bottom temperatures were recorded throughout each shrimp survey set with a continuous temperature recorder (Vemco Ltd.) attached to the headline of the trawl. Trends in these data generally agree with groundfish survey data, however the latter is used in the analysis because of the more complete time series.

It is hypothesized that warmer water temperatures have a negative influence on shrimp populations because of the decreased fecundity associated with increased growth rates, decreased size at transition and decreased maximum size as described above.

July SST

Sea surface temperatures are calculated as average temperatures within defined rectangles encompassing the shrimp holes, using the Oceans Sciences and Biological Oceanography Section SST databases.

Negative correlations between SSTs and lagged population estimates are common for the southern *P. borealis* stocks, including the Scotian Shelf, and are presumably also related to growth and fecundity, possibly because of diurnal migrations to near surface water.

RV Capelin abundance

This is calculated as the average catch/tow in numbers from the June shrimp survey.

Capelin are the most common bycatch species both in the Scotian Shelf trawl fishery and the June shrimp survey. Here they have been shown to increase in abundance during cold periods which are also favourable to shrimp and so can be considered a sympatric species. It can therefor be considered an indicator of conditions favourable to the production of shrimp. Although there are other species which are associated with shrimp and cold water e.g. Greenland halibut and snow crab also increased during the recent increase in shrimp abundance, capelin is the only fish species which goes through the Nordmore grate of the survey trawl at all sizes/ages and is caught in numbers that are likely proportional to its overall abundance.

FISHING MORTALITY

Total Exploitation Rate

An overal exploitation rate is calculated as the total catch weight divided by the RV biomass estimated using the swept area method.

The RV biomass estimate has been shown to be underestimated by as much as 25% because of lack of coverage in shallow areas surrounding the shrimp holes, consequently the exploitation rate is probably overestimated.

Female Exploitation Rate

This is calculated as the estimated weight of females in the catch divided by the weight of females in the population from the survey i.e. the SSB. The industry-funded port sampling program which began in 1995 continued in 2001 and allows determination of the catch composition by developmental stage and size from detailed analyses as per survey samples. Samples were collected throughout the fishery in all areas from all fleet components including vessels <65' LOA landing mainly in Canso and vessels >65' LOA landing mainly in Arichat. The number of samples per month and area was allocated in proportion to weight caught. Catch at length was determined from a weighted length frequency and a length-weight relationship.

Female exploitation is of interest because the shrimp fishery is selective for the larger females. It can be considered one measure of the impact of fishing on the reproductive potential of the stock.

Proportion of females in catch

The proportion of females in the catch by weight to the total catch weight is calculated from commercial samples which identify females, lengths and individual weights as per survey samples.

A decrease in this indicator could indicate a decrease in the number of larger shrimp in the population due to fishing removals and an increased reliance on smaller animals i.e. possible growth overfishing and/or recruitment overfishing. It should be interpreted cautiously and in combination with other indicators, since it could also indicate good recruitment conditions and difficulty in avoiding young shrimp.

Fishing during ovigerous period

This is calculated as the percent of the total catch caught during August-March, the usual period when females are carrying eggs.

Since most eggs are laid by a single year class (i.e. age 5) enough females must escape the fishery to prevent recruitment overfishing. The fishery has generally concentrated in the non-ovigerous period with most of the catch taken during May-July, however as TACs increased an increasing amount of the catch has been taken during the ovigerous period. This indicator should

be included with spawning stock biomass and size at transition when considering the population's overall reproductive capacity, since their negative effects are probably cumulative. For example, the minimum SSB of 4,300 mentioned above would be considerably less in terms of effective reproductive capacity if most is taken before egg hatching.

Traffic Light Summary

Individual traffic light indicators were summarised using the "direct" method. Each indicator is given a value according to its colour i.e. green = 3, yellow = 2 and red = 1, and a simple average is calculated. This average is assigned a "summary colour" according to limits determined by the probability distribution of possible outcomes i.e. the limits between red, yellow and green are set so that each of the three summary colours has an equal probability of being assigned in a random set of individual indicator colours/values. The RAP review committee emphasised that the summary is difficult to interpret and should not be a consideration in the advice, because issues such as weighting of indicators and harvest rules associated with any particular summary have not been resolved.

Simulations

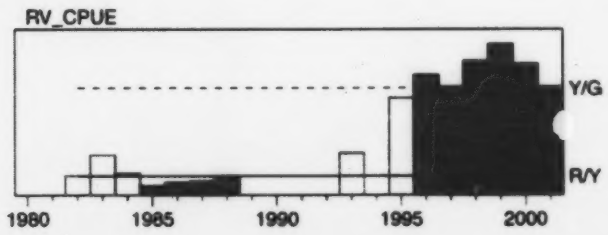
An age based model was used to simulate Eastern Scotian Shelf shrimp population dynamics in order to determine what degree of intervention would be necessary to prevent decrease of the spawning stock biomass below a reference level during an environmentally and fishery induced population downturn. The reference level was taken as the average spawning stock biomass during the period of low abundance in the 1980s i.e. 4000mt. This seemed reasonable since the population recovered from this level despite low but increasing levels of exploitation. The model was essentially deterministic in that key input parameters, including the S-R relationship and natural mortality, were set to obtain population fluctuations in size and frequency near those observed during the period when abundance estimates were available. Environmental influences were assumed to have a strong affect on the population as evidenced by the large increase in abundance during the late 1980s and early 1990s despite increasing exploitation, apparently due to the decrease in groundfish predators and concurrent decrease in water temperatures. This was simulated by changing natural mortality in 0.03 unit increments between 0.3-0.6, a range similar to values in the literature for pandalids. Growth, selectivity, and size at sex reversal were set to average values seen on the Scotian Shelf. The S-R relationship used was dome-shaped, with a moderate decrease in recruitment at SSBs above 5000mt, as might be expected from density dependant processes such as egg parasitism and growth. This produced a 20 yr cycle with maximum and minimum spawning stock biomasses near those observed. Fishing was started at a TAC of 3000mt during the period of increasing abundance and was increased quickly to 5000 mt, a scenario similar to that of the Scotian Shelf. As the population began to decrease due to the combined effects of fishing and increasing natural mortality TACs were decreased in order to keep SSB above the reference level.

RESULTS AND DISCUSSION

Input data for the traffic light analysis are given in Table 3. These data are graphed in the uncaptioned figures immediately following the indicator headings below.

ABUNDANCE

Research Vessel Abundance Index



The stratified survey estimate decreased for the second year in a row, as did the estimates for 3 of the 4 areas (Figure 2). Only SFA 14 (Misaine Hole) showed an increase in 2001, although it appeared to have been decreasing for the previous two years. It should be noted that the estimate for SFA 15 (Canso Hole) would be significantly lower if the initial estimate obtained on 28-29 May (sets 3-17, Table 4) had been used. Initial catch rates in this area were consistently low, averaging only 11% of the previous year's survey. However, reports of good commercial catch rates in parts of area 15 shortly before the survey especially in relatively shallow water, coupled with unusually low temperatures (~1.5 °C) during the survey (see RV bottom temperatures below) suggested that shrimp migration into the deeper (>200m) water from the slightly shallower overwintering depths had been delayed this year (see Figures 8-9). When catch rates and temperatures in other areas appeared more normal it was decided to repeat area 15 at the end of the survey i.e. during 18-19 June. Catch rates had nearly quadrupled when sets 3-17 were repeated on identical fishing tracks (sets 61-64, 66-75, Table 4) however they were still significantly lower than the previous year. It had been apparent from fishing other areas that variances had increased significantly, with one or two very large sets contributing to much of the estimate. This, together with reports from the fishery that shrimp were 'bunching up' and that catch rates were exceptional in some spots and very poor only a short distance away, suggested that the random allocation had missed any large concentrations in area 15. Consequently, a comparative set (set 65, Table 4) was allocated in SFA 15 at a location where the captain had obtained good catches earlier in the spring. This set was exceptional (1662 kg), and nearly doubled the average catch rate for SFA 15 but this was still significantly lower than last year. This set has not been included in any of the analysis presented below because it did not meet the sampling requirement of randomness. Note that its inclusion would increase the overall stratified estimate to 192.7 from 183.3 kg/tow, i.e. by only 5%. Similarly, the overal biomass estimate for 2001 was 25,029, but would have been 26,305 mt had set 65 been included.

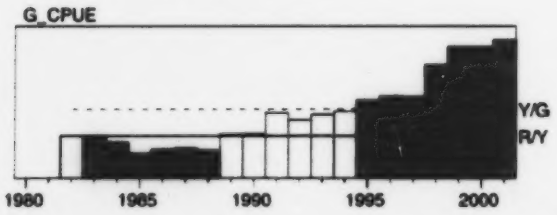
It is noteworthy that SFA 13 has generally registered the lowest catch rates of all 4 areas and has decreased along with the others despite only relatively light fishing in this area (Table 1).

The earlier survey period (1982-1988) used a different trawl than the more recent period and there were no direct intercalibrations (comparative fishing experiments) between series. The two series were intercalibrated using a factor which only incorporated the difference in trawl wing spreads. Shrimp trawl efficiencies can vary significantly even between shrimp trawls with nearly identical wing spreads (Koeller et al 1997). In addition to being significantly smaller, the

trawl used during the earlier series did not use a sorting grate to exclude bycatch and had a much lower headline height compared to the modern shrimp trawls used in the more recent series. It is therefore likely that the trawl used during the 1982-1988 surveys was less efficient at catching shrimp than the trawl used since 1993. It follows that the differences in catch rates between the two series are probably exagerated and the 2001 estimate, just barely green, would be yellow if the same gear had been used throughout.

Interpretation: The decrease in the survey estimate for two years in a row indicates that the stock is in decline, although it is still at a relatively high level compared to the low abundances of the 1980s. Fishing does not appear to be the main cause of these declines, or at least, it is not the only cause.

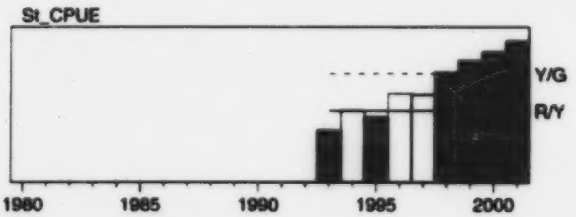
Gulf Vessels Catch Per Unit Effort



The increase in the Gulf Vessel CPUE appeared to stabilize in 1999, and has remained at a high level since then. A small (5%) increase ocurred in 2001.

Interpetation: In light of changes in other indicators, i.e. the decrease in the survey estimate and evidence of increased aggregation from both survey and fishery indicators of dispersion, the increase in this indicator is apparently due to higher densities in these aggregations. Higher densities combined with decreasing abundance may be a signal that the population is under stress.

Commercial trawler standardized catch per unit effort

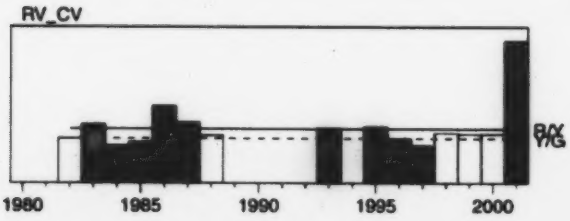


The standardized CPUE series increased by 8% in 2001, and it has increased every year except for two of the 9 year series. The parallel trend in both survey and CPUE series broke down in 2000 with the survey showing decreases and CPUE showing increases in the last two years (Figure 3A). Unstandardized CPUEs for all areas (Figure 3B) also increased in 2001.

Interpretation: As with the other CPUE series the increase in this indicator in 2001 is interpreted to be due to better catches in denser and smaller shrimp aggregations and not to an

increase in abundance. Higher densities combined with decreasing abundance as indicated by the survey index may be a signal that the population is under stress.

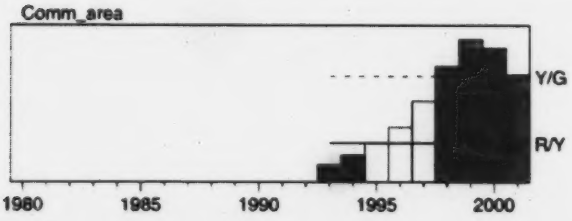
Research vessel coefficient of variation



This measure of dispersion increased significantly in 2001. An increase in CV ocurred in all areas except SFA 15 (Figure 4), however, the CV in this area would also have increased had the non-random set (65) been included. It is possible that this increased aggregation is an indication that the population is under some environmental stress. However, colder temperatures which are generally associated with favourable conditions for shrimp, were recorded in 3 of the 4 areas during 2001. Whatever the cause, increased aggregation would make the population more vulnerable to fishing and so is considered a negative development in any case. The distribution of catches from all surveys shown in Figure 5 in relation to bottom temperatures also shows a greater variation in 2001 compared to earlier years.

Interpretation: shrimp aggregated more than usual during 2001 in at least three, and probably all four fishing areas, accounting for the increases in the CPUE indicators.

Commercial fishing area



The area with commercial catch rates >250kg/hour increased since the beginning of the series until 1999, when it began to decrease. The area with catch rates >150kg began to decrease in 1997, while the interval with the highest catch rates (>450) has continued to increase (Figure 6). This pattern is consistent with a concentration of the resource in a smaller area and appears to be a longer term phenomenon. Increased aggregation was noted by fishers in interviews conducted in 2000 and 2001. The annual distribution of effort since 1995 is shown in Figure 7. Note the concentration of effort in the southeastern part of the Whitehead Hole (SFA 15) – the area where Set 65 was located (see Research Vessel Abundance Index). Trawl fishers have also noted that fishing has ocurred in shallower water in the offshore area in more recent years. This appears to be supported by log data, which shows a decrease in average fishing depth from 1995-1999, with some increase since then (Figure 8A). There is a seasonal component in fishing depth (Figure 8B), with fishing in the deepest depths ocurring in June and July. This corresponds

approximately to the seasonality in catch rates and counts, and is probably due to migrations of larger shrimp driven by daylength (Figure 9). The data in Figures 8 and 9 has been limited to the offshore because fishing in the shallow inshore area beginning in 1998 would have masked the local changes in depths seen in Figure 8A. Increases in trap catch rates directly off Canso (Figure 10) imply increased movement of the large, mainly female shrimp which constitute most of the catch into shallow nearshore areas within the inshore area, consistent with the overal increased aggregation of shrimp shown by survey and commercial data, fisher interviews, and the shallower distribution of offshore fishing effort. After the initial decrease in trap catch rates in 1997 attributed to removal of accumulated large animals in the small trapping area off Canso average trap catch rates have increase annually since 1998, with 2001 showing the largest catches and catch rates in the short history of the fishery (Table 1, Figure 10).

Intrepretation: Scotian Shelf shrimp are aggregating in smaller areas of higher density, and in slightly shallower water, possibly in response to unfavourable environmental conditions. Since this appears to be a longer term phenomenon, it was apparently not due to the colder temperatures observed in 2001, but may be linked to the overall rise in surface and bottom temperatures in recent years. Also, since depth is directly related to size (Koeller 2000), a smaller (in average size) population will be distributed in shallower water.

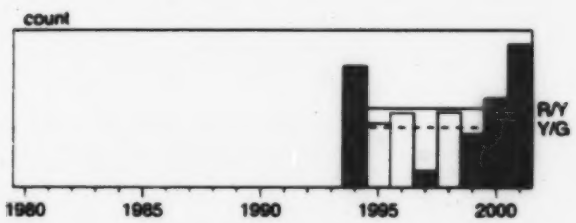
Industry perspective

Although the number of fishers interviewed decreased considerably in 2001, questionnaire results (Table 5) generally confirm trends in a number of indicators including increased aggregation, shallower fishing depths and increased catch rates.

Questionnaire results are usefull in the interpretation of trends seen in other indicators and are not included in the Traffic Light indicator table or summary.

PRODUCTION

Commercial counts

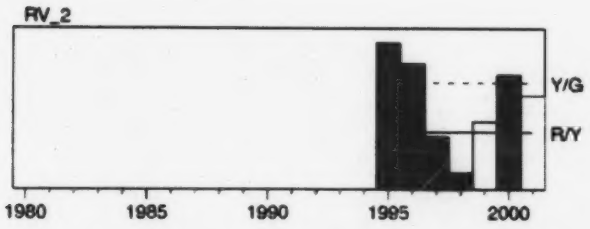


Counts (numbers/pound) appear to have increased since 1997 despite the increased use of square meshed codends, probably due to removal of accumulated large animals in the population. The ranges and variation around this parameter are large (Figure 11A), and there is a seasonal component, with counts decreasing to a minimum in July and increasing thereafter (Figure 9, 11B). The length composition of the catch (Figure 12) has changed considerably over the last few years and indicates that there were proportionally fewer shrimp caught at the largest sizes, in

agreement with some fisher's observations (questionnaire comments on Biology) and decreases in the proportion of females in the catch.

Interpretation: Commercial counts have increased due to a decrease in the number of larger shrimp in the population.

RV abundance at age 2

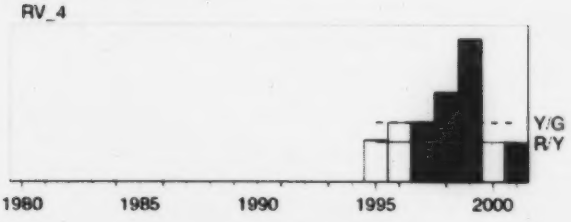


Age 2 abundance (i.e. 1999 year-class in 2001) was about average for the 7 year survey period, however this is not a reliable estimator of recruitment to the population. For example, the strong 1995 year class has one of the lowest estimates at Age 2 (Table 6), and the 1998 year class was among the largest at Age 2 in 2000 but is below average at Age 3 in 2001. On the other hand, the 1996 year class has been poor in all years and had the lowest estimate at Age 2, consequently this indicator may be of some value in detecting very poor year classes. The apparent failure of the 1996 year class has been attributed to the high incidence of egg disease that year.

Population estimates at length are given in Figure 13. The year classes are identified in this figure as are the length frequencies for transitional + primiparous and the multiparous shrimp which usually represent separate year classes within the last "blended" mode. Population estimates at length for each of the four survey strata are shown in Figure 14.

Interpretation: recruitment to the population appears to be about average but the estimate is unreliable.

RV abundance at age 4

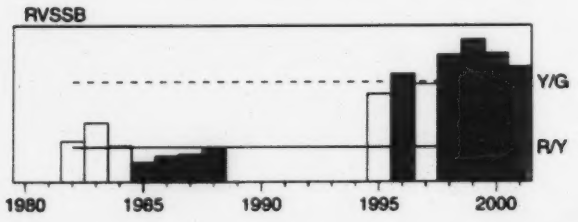


The abundance of age 4 shrimp in 2001 was the second lowest of the 7 year series. The abundance of age 3 shrimp was also below average (Table 6), consequently recruitment to the fishery during the next few years does not appear to be good. In contrast, Age 5+ abundance was above average due to the maturation of the 1995 year class whose progession through the fishery is clearly evident in Figure 13. The large last mode in 2001 consists of the accumulation of two large year classes i.e. 1994 and 1995. The 1995 year class began to change sex in 2000.

Due to slower growth, presumably due to density dependant effects, the 1995 year class had not completed sex change in 2001 and a considerable number from this year class remained male. Consequently it will take 3 years for this year class to complete sex change.

Interpretation: the large 1995 year class supported the fishery in 2001 as expected, however the abundances of year classes that will be recruiting to the fishery in 1-2 years is below average. The population can therefor be expected to continue decreasing for the next few years. Unless the aggregation of the resource in smaller areas seen in the last two years continues, decreases in catch rates should be expected in 2002.

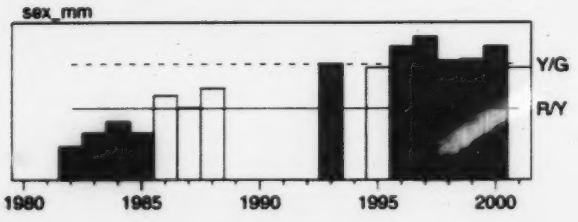
RV spawning stock biomass (Females)



Research vessel spawning stock biomass estimates decreased during the last 2 years but at 14,229 mt in 2001 it is still well above the low SSBs of the 1980s (average 4,272) when the population was increasing. It is therefore unlikely that the decreased recruitment seen in recent years is due to overfishing of spawners. It should be noted that the earlier survey time series did not include inshore sampling. Assuming that shrimp were as abundant inshore during the earlier period as they were during the latter, i.e. they contributed about 25% of the total biomass, this would increase the average SSB in the earlier period to about 5600 mt.

Interpretation: Spawning stock biomass is decreasing but is still well above the low levels of the 1980s when the population was increasing. Decreases in spawing stock biomass does not appear to be the cause of the recent decline in recruitment.

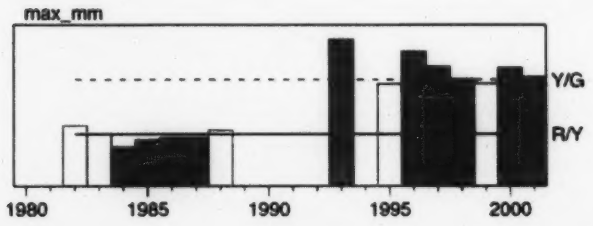
Average size at sex transition (L_t)



The overall average size at sex transition decreased in 2001, however there has been no clear trend that would suggest increasing growth rates, and size at transition remains substantially higher than the period of faster growth during the 1980s. Annual changes are generally reflected in all regions (Figure 15A).

Interpretation: There has been no major change in growth rates but an increase in 2001 could be a signal that a period of increasing growth rates and decreased population fecundities may be underway.

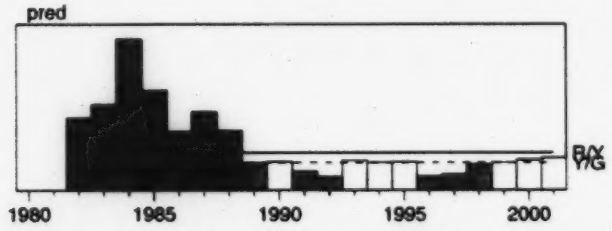
Average maximum size (L_{max})



Average maximum size in the population decreased in 2001. This indicator appears to have a decreasing trend since 1996 but maximum size remains substantially higher than the period of faster growth during the 1980s. As with size at transition, annual changes are generally reflected in all regions (Figure 15B). The consistently smaller maximum sizes in area 13 are attributed to faster growth rates caused by higher temperatures in this area. The consistently lower abundances in this area are attributed to lower fecundities of the smaller animals.

Interpretation: There has been no major change in growth rates but a decreasing trend in maximum size during the last few years suggest that growth rates are increasing and may eventually lead to decreased population fecundities.

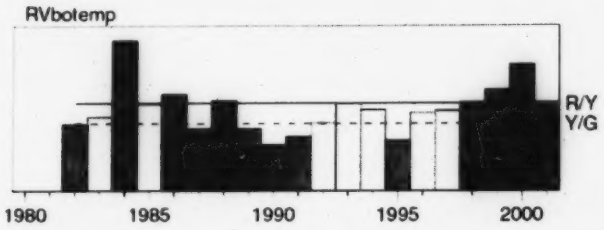
Predation



There has been a slight increasing trend in groundfish abundance in recent years, however, groundfish abundance remains well below the high levels during the 1980s when the shrimp population was low.

Interpretation: natural mortality due to predation may be increasing slightly but remains well below the high values of the 1980s that probably contributed to the low shrimp abundances during that period.

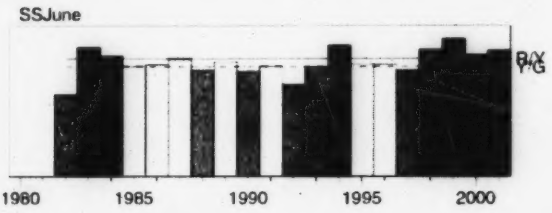
RV (groundfish survey) bottom temperatures



Bottom temperatures on the shrimp grounds have fluctuated during the groundfish survey time series but in general they decreased during the 1980s and increase during the 1990s. Temperatures from shrimp surveys by SFA generally show the same trends as data from groundfish surveys (Figure 16).

Interpretation: decreasing bottom temperatures during the 1980s resulted in decreasing growth rates, and corresponding increases in size at transition, maximum size and fecundity. Increasing bottom temperatures during the 1990s have not yet resulted in significant increases in growth rates, probably due to density dependant effects.

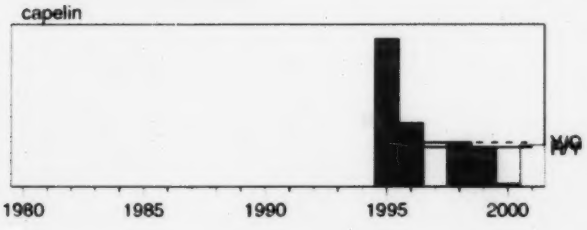
June SST



Surface temperatures are inversely related to shrimp abundance with a lag of 4-5 years. The below average temperatures prevalent during the late 1980s and early 1990s appear to have led to the high abundances in the mid to late 1990s.

Interpretation: the above average temperatures during the late 1990s are likely to lead to decreased abundances in the early part of the 2000s and may be associated with the decline observed since 2000.

RV Capelin abundance

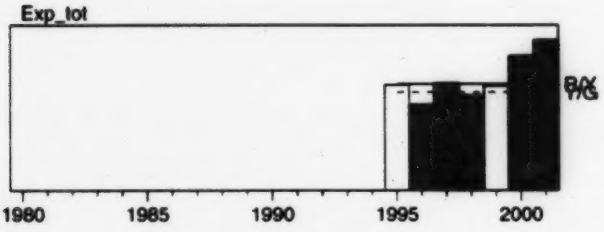


The capelin abundance index has shown a decreasing trend since the high abundances in the mid 1990s. The index increased slightly in 2001.

Interpretation: Conditions which resulted in high production of capelin and shrimp in the mid 1990s may be changing to ones less favourable to these species.

FISHING MORTALITY AND IMPACT

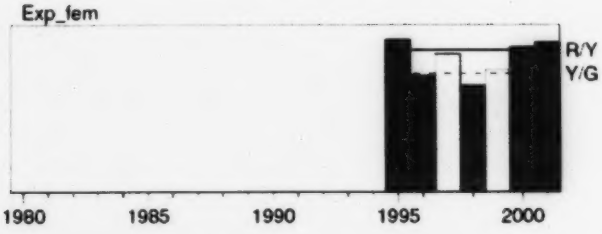
Exploitation Rate



Overall exploitation rate has increased annually since 1998 partially due to increases in TACs. The increases in 2000 and 2001 were particularly large due to decreases in the survey biomass estimates during those years. The current exploitation rate of 19%, while lower than most other shrimp stocks in the Northwest Atlantic, is beginning to approach these values. It has previously been noted that the Scotian Shelf shrimp stock is likely to be more vulnerable to over-exploitation both due to the cumulative effect of negative environmental influences and fishing pressure, and the small areas of suitable habitat (Koeller 2000). Exploitation rates by SFA are given in Table 7. SFA 15 experienced the highest exploitation rate in the series (33.8%) in 2001, presumably due to the increased aggregation in this area and resulting vulnerability to the fishery.

Interpretation: Exploitation rates have increased to levels which should be of concern to managers.

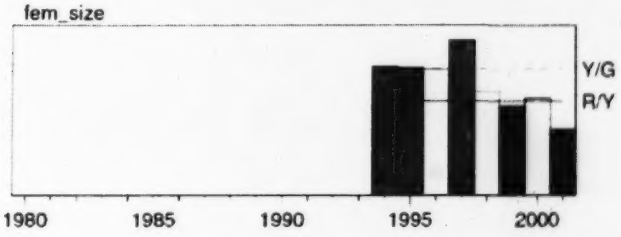
Female Exploitation Rate



Female exploitation rates have increased since 1998 as TACs were increased.

Interpretation: Female exploitation rates have increased and in combination with other factors (fishing during the ovigerous period, decrease in proportion of females in catch, size at sex change and maximum size) may be impacting on the population's reproductive capacity.

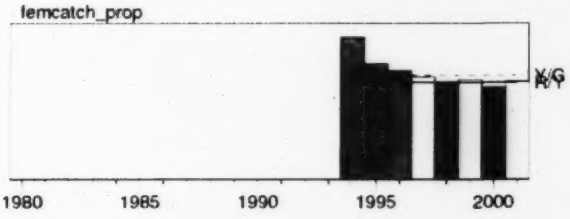
Mean size of females in catch



The average size of females in the catch has decreased since the mid 1990s.

Interpretation: The average size of females in the catch has decreased as the larger animals were selectively removed from the population by the fishery. Since fecundity is directly related to size this, in combination with other factors (fishing during the ovigerous period, increased female exploitation, size at sex change and maximum size), may be impacting on the reproductive capacity of the population.

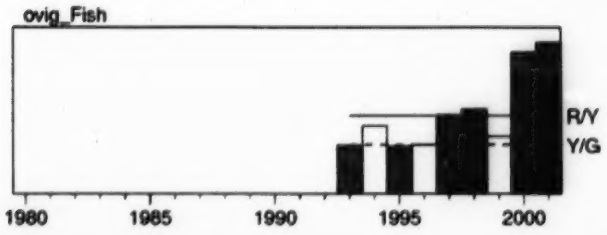
Proportion of females in catch



The proportion of females in the catch has shown a decreasing trend since sampling began in 1994. The catch at length (Figure 12) also continues to show a decrease in the proportion of larger shrimp in the catch.

Interpretation: the proportion of females in the catch has decreased as the larger animals were selectively removed from the population by the fishery. Since fecundity is directly related to size this, in combination with other factors (fishing during the ovigerous period, increased female exploitation, size at sex change and maximum size), may be impacting on the reproductive capacity of the population. Also, increasing exploitation of the smaller, non-female part of the population could result in growth overfishing.

Fishing during ovigerous period

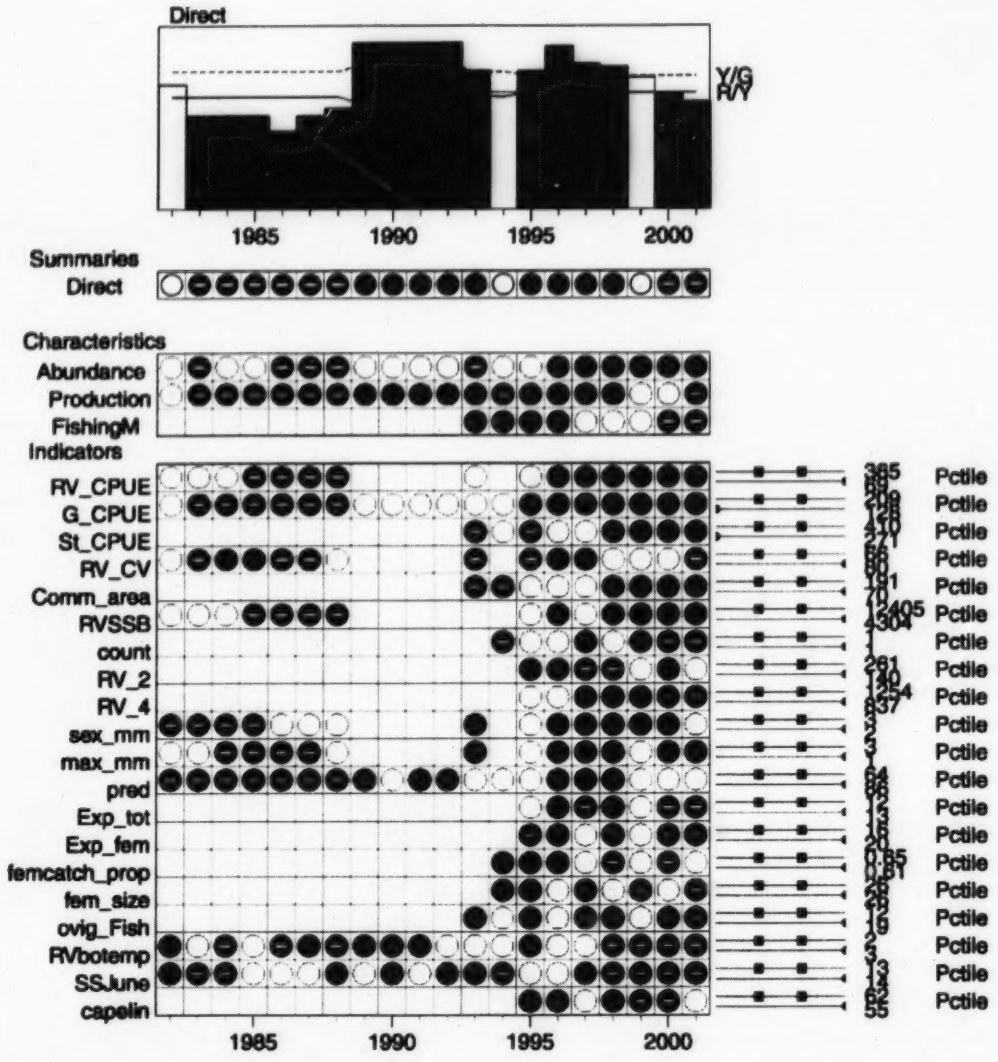


Fishing during the ovigerous period has increased significantly during the last 2 years, largely due to the longer time required to catch larger TACs by a relatively small fleet of vessels, many of which are also engaged in other fisheries. In addition, quota transfers have ocurred and many vessels now fish several individual quotas, further extending the length of the season.

Interpretation: Fishing is having a greater impact on population reproductive potential by removing ovigerous females before their eggs have hatched.

Traffic Light summary

The direct summary of indicators below shows 4 successive green lights during the period of increasing abundances and TACs beginning in 1995, when the DFO-industry survey series started. An initial yellow summary light in 1999 signalled the possibility of an end to the period of abundance and the beginning of a decline. Two successive red lights for 2000-2001 confirms this decline and indicates that more severe intervention is required to prevent further increases in exploitation rates and an accellerated population decline due to the combined effects of fishing and unfavourable environmental conditions. Note that the abundance characteristic continues to show green lights, while production and fishing mortality are both red in 2001.



Simulation results

Figure 17 gives simulation results, including changes to the spawning stock biomass without fishing and with TACs increased rapidly to 5000mt during the period of population increase, then adjusted to prevent the spawning stock from decreasing below 4000mt during an environmental and fishery induced downturn. Changes in TAC required to maintain SSBs near the reference level were substantial and rapid, i.e. a 70% decrease within 2 yr. and eventual fishery closure. These results suggest that significant management intervention may be required to prevent a shrimp stock subjected to both unfavourable environmental conditions and fishing pressure from decreasing rapidly below previous historical low levels of spawning stock biomass.

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Table 1. TACs (trawls) and catches (trawls and traps) from the eastern Scotian Shelf shrimp fishery 1980-2001.

	TAC		Catch					
	Trawl	Trap	Trawl				Trap	
			SFA					
			13	14	15	Total		Total
1980	5021		491	133	360	984		984
1981	-		418	26	10	454		454
1982	4200		316	52	201	569		569
1983	5800		483	15	512	1010		1010
1984	5700		600	10	318	928		928
1985	5560		118	-	15	133		133
1986	3800		126	-	-	126		126
1987	2140		148	4	-	152		152
1988	2580		75	6	1	82		82
1989	2580		91	2	-	93		93
1990	2580		90	14	-	104		104
[1]1991	2580		81	586	140	804		804
1992	2580		63	1181	606	1850		1850
[2]1993	2650		431	1279	317	2044		2044
[3]1994	3100		8	2656	410	3074		3074
1995	3170		168	2265	715	3148	27	3175
1996	3170		55	2299	817	3171	187	3358
1997	3600		570	2422	583	3574	222	3773
1998	3800		562	2014	1223	3800	131	3931
1999	4800	200	717	1521	2464	4702	149	4851
2000	5300	200	473	1822	2940	5235	201	5436
2001	4700	300	692	1298	2515	4505	263	4768

[1] Nordmore separator grate introduced.

[2] overal TAC not caught because TAC for SFA 14 and 15 was exceeded.

[3]individual SFA TACs combined

Table 2. Number of active vessels and total licences (in brackets) for the Scotian Shelf shrimp fishery.

	Exp. Trap	Trawl	
Year	S-F[1]	S-F[2]	Gulf[3]
1995	4	24(23)	6(23)
1996	9(17)	21(24)	6(23)
1997	10(17)	18(23)	6(23)
1998	15(26)	17(28)[4]	10(23)[5]
1999	15(22)	19(28)[4]	10(23)[5]
2000	12(21)	18(32)[6]	10(23)[5]
2001	10(28)	18(28)[4]	10(23)[5]

[1] All but one active trap licences are vessels < 45'. These vessels are allocated 10% of the TAC, with the uncaught portion reallocated to the trawl fleet

[2] These vessels receive 75% of the trawl quota according to a Federal-Provincial agreement that expires December 31, 2002. Inactive NAFO 4X licences (15) not included in total ( ).

[3] All licences 65-100' LOA. Eligibility to fish in Scotia-Fundy for 25% of the trawl quota split under the Federal-Provincial agreement that expires December 31, 2002.

[4] temporary allocation divided among 5 vessels.

[5] temporary allocation divided among 4 vessels.

[6] temporary allocation divided among 9 licences.

Table 3. Input data for traffic light analysis.

	RV_CPUE	G_CPUE	St_CPUE	RV_CV	Comm_area	RVSSB	count	RV_2	RV_4	sex_mm	max_mm
1982	68.78	128.00	NAN	65.50	NAN	5040.65	NAN	NAN	NAN	1.00	1.54
1983	142.50	127.70	NAN	86.00	NAN	7323.05	NAN	NAN	NAN	1.40	1.34
1984	78.07	109.50	NAN	55.30	NAN	4460.96	NAN	NAN	NAN	1.75	1.00
1985	33.61	75.40	NAN	60.40	NAN	2417.71	NAN	NAN	NAN	1.40	1.18
1986	46.02	87.30	NAN	113.10	NAN	3187.87	NAN	NAN	NAN	2.55	1.24
1987	50.84	90.70	NAN	89.20	NAN	3424.46	NAN	NAN	NAN	2.18	1.24
1988	62.76	85.10	NAN	70.10	NAN	4047.02	NAN	NAN	NAN	2.77	1.43
1989	NAN	133.40	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
1990	NAN	134.50	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
1991	NAN	197.90	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
1992	NAN	176.30	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN	NAN
1993	149.70	193.00	196.59	80.32	31.00	NAN	NAN	NAN	NAN	3.51	3.76
1994	NAN	202.40	271.71	NAN	48.00	NAN	2.28	NAN	NAN	NAN	NAN
1995	346.04	233.80	246.63	82.80	71.00	10912.15	1.20	358.50	875.92	3.40	2.62
1996	427.84	245.90	333.22	65.16	99.00	13368.38	1.40	307.34	1247.63	4.03	3.45
1997	386.00	245.50	329.59	55.47	146.00	12100.80	0.31	128.85	1257.47	4.33	3.07
1998	476.76	341.00	415.02	73.64	209.00	15707.48	1.42	39.89	1883.71	3.60	2.74
1999	536.80	396.00	459.13	72.20	258.00	17607.48	1.00	165.63	3010.18	3.64	2.63
2000	466.72	396.00	492.88	72.00	242.00	15893.36	1.67	280.34	0.00	4.04	3.03
2001	366.64	417.00	533.36	209.00	194.00	14228.86	2.69	229.74	819.72	3.39	2.79

	pred	Exp_tot	Exp_fem	Fcatch _prop	ovig_Fish	RVbtemp	SST June	capelin
1982	165.89	NAN	NAN	NAN	NAN	1.98	9.67	NAN
1983	196.36	NAN	NAN	NAN	NAN	2.20	15.15	NAN
1984	347.25	NAN	NAN	NAN	NAN	4.46	14.14	NAN
1985	228.63	NAN	NAN	NAN	NAN	2.58	12.96	NAN
1986	133.96	NAN	NAN	NAN	NAN	2.87	13.12	NAN
1987	179.76	NAN	NAN	NAN	NAN	1.85	13.81	NAN
1988	136.44	NAN	NAN	NAN	NAN	2.68	12.48	NAN
1989	62.94	NAN	NAN	NAN	NAN	1.85	13.49	NAN
1990	65.55	NAN	NAN	NAN	NAN	1.38	12.40	NAN
1991	43.42	NAN	NAN	NAN	NAN	1.62	12.97	NAN
1992	31.00	NAN	NAN	NAN	NAN	2.02	10.86	NAN
1993	68.33	NAN	NAN	NAN	11.91	2.60	12.86	NAN
1994	64.36	NAN	NAN	0.89	16.71	2.41	15.42	NAN
1995	65.45	13.33	21.04	0.72	11.69	1.51	13.20	207.16
1996	32.04	10.86	16.11	0.68	12.07	2.32	13.17	88.63
1997	36.21	13.57	19.08	0.64	19.32	2.38	12.47	61.67
1998	59.61	12.08	14.73	0.60	20.60	2.63	14.89	62.20
1999	64.02	13.17	16.90	0.63	14.11	3.01	16.16	53.94
2000	69.96	17.00	20.00	0.58	34.57	3.74	14.23	3.64
2001	74.18	19.01	20.67	0.61	37.00	2.62	14.79	58.49

Table 4. Set statistics from DFO-idustry survey CA0101 conducted by MV Carmel 5 May 27 - June 19 2001. Italics under the set heading indicate comparative fishing sets, while bold numbers indicate non-random sets conducted at locations with previous good commercial catches (not included in analyses). Italics under wingspread and headline height headings indicate sets with poor or no readings from the trawl mensuration equipment and the use of survey averages in swept area estimates.

SET	SFA	DATE	LAT.	LONG.	SPEED (kts)	DIST. (n. m.)	WING. (m)	HEIGHT (m)	DEPTH (fth)	TEMP (°C)	RAW CATCH (kg)	stand. catch	DENSITY (gm/m² or m.t./km2)
1	17	27-May-01	45°22.14'	61°02.85'	2.4	1.20	*16.9*	6.1	53	1.3	114	122.2	3.0
2	17	27-May-01	45°28.05'	60°50.63'	2.4	1.20	*16.9*	6.0	69	1.6	87	93.5	2.3
3	15	28-May-01	45°01.39'	60°55.85'	2.1	0.99	17.4	6.2	111	1.7	3	4.0	0.1
4	15	28-May-01	44°56.81	61°03.67'	2.1	1.06	17.3	6.2	106	1.5	58	68.5	1.7
5	15	28-May-01	44°53.43'	60°58.58'	2.1	1.00	17.4	5.9	136	1.6	6	7.4	0.2
6	15	28-May-01	44°50.33'	60°55.23'	2.4	1.18	16.6	5.7	132	1.4	49	54.8	1.4
7	15	28-May-01	44°58.98'	60°45.52'	2.2	1.12	16.5	5.9	105	1.6	18	21.4	0.5
8	15	28-May-01	44°54.99'	60°45.21'	2.4	1.20	*16.9*	*6.1*	110	1.6	1	1.0	0.0
9	15	28-May-01	44°51.00'	60°46.97'	2.3	1.21	*16.9*	*6.1*	147	1.5	13	13.5	0.3
10	15	28-May-01	44°51.53'	60°38.76'	2.3	1.12	17.2	*6.1*	146	1.5	48	53.7	1.3
11	15	28-May-01	44°53.69'	60°25.33'	2.3	1.16	*16.9*	*6.1*	134	1.7	5	5.5	0.1
12	15	29-May-01	44°58.95'	60°14.01'	2.1	0.96	16.3	6.0	108	1.5	37	51.8	1.3
13	15	29-May-01	44°51.02'	60°16.83'	2.3	1.02	16.8	6.2	138	1.7	7	9.2	0.2
14	15	29-May-01	44°46.63'	60°17.13'	2.4	1.06	17.1	6.3	180	1.7	4	4.9	0.1
15	15	29-May-01	44°40.43'	60°19.45'	2.5	1.16	16.8	6.6	122	1.6	1	1.0	0.0
16	15	29-May-01	44°42.14'	60°13.14'	2.3	1.08	17.0	6.2	122	2.2	198	234.6	5.8
17	14	29-May-01	44°39.11'	60°00.65'	2.5	1.26	16.7	6.2	107	2.4	32	33.2	0.8
18	14	29-May-01	44°43.34'	59°56.81'	2.4	1.15	16.1	5.9	100	1.9	196	230.9	5.7
19	14	29-May-01	44°48.29'	59°55.54'	2.3	1.11	17.0	5.9	127	2.1	253	290.8	7.2
20	14	29-May-01	44°53.94'	59°58.02'	2.3	1.17	16.7	5.8	107	2.0	124	137.8	3.3
21	17	30-May-01	45°06.92'	59°54.73'	2.3	1.07	17.5	6.1	80	2.2	0	0.1	0.0
22	17	30-May-01	45°13.78'	59°56.52'	2.3	1.16	16.3	6.0	101	2.3	131	149.9	3.7
23	17	30-May-01	45°20.71'	59°45.88'	2.3	1.15	16.4	5.9	75	2.4	3	3.1	0.1
24	17	30-May-01	45°20.50'	60°00.83'	2.3	1.14	17.0	6.2	108	2.2	254	284.3	7.4
25	17	30-May-01	45°17.19'	60°20.74'	2.4	1.15	16.2	5.9	95	2.2	361	420.5	10.4
26	17	30-May-01	45°19.11'	60°26.15'	2.1	1.00	16.1	6.0	82	1.9	2	2.4	0.1
27	17	30-May-01	45°27.37'	60°23.61'	2.3	1.15	16.1	6.4	112	2.2	2	2.1	0.1
28	17	30-May-01	45°33.13'	60°21.51'	2.3	1.17	16.8	6.0	95	2.2	76	83.8	2.1
29	17	30-May-01	45°32.37'	60°13.98'	2.4	1.12	17.8	6.6	103	2.3	3	3.0	0.1
30	17	31-May-01	45°38.49'	60°00.46'	2.3	1.05	16.5	6.1	80		4	4.6	0.1
31	17	31-May-01	45°30.01'	60°01.55'	2.2	1.07	16.0	6.1	99	2.2	73	92.1	2.3
32	17	31-May-01	45°30.47'	60°33.26'	2.2	1.04	16.3	6.7	84	2.1	170	217.9	5.4
33	17	31-May-01	45°24.68'	60°38.67'	2.2	1.04	16.2	6.5	83	1.8	1020	1313.8	32.6
34	13	14-Jun-01	45°38.23'	59°04.71'	2.4	1.14	17.3	6.0	140	3.8	279	308.4	7.7
35	13	14-Jun-01	45°35.59'	58°54.90'	2.3	1.15	22.2	5.8	125	3.5	128	109.1	2.7
36	13	14-Jun-01	45°41.90'	58°46.94'	2.3	1.13	16.6	*6.1*	141	4.0	308	356.2	8.8
37	13	14-Jun-01	45°42.62'	58°55.00'	2.4	1.16	16.6	6.3	131	3.8	34	39.0	1.0
38	13	14-Jun-01	45°42.56'	59°02.20'	2.3	1.19	16.8	6.1	117	3.7	15	15.8	0.4
39	13	14-Jun-01	45°50.37'	58°56.24'	2.5	1.20	16.7	5.6	113	3.5	7	7.4	0.2
40	13	14-Jun-01	45°47.76'	58°43.88'	2.1	1.06	17.6	5.8	147	4.8	165	192.9	4.8
41	13	14-Jun-01	45°52.30'	58°42.60'	2.3	1.13	17.8	*6.1*	143	4.5	40	43.1	1.1

42	13	14-Jun-01	45°52.04'	58°36.94'	2.5	1.20	16.5	6.0	140	4.1	229	252.0	6.3
43	13	14-Jun-01	45°52.10'	58°32.51'	2.5	1.21	16.3	5.7	119	3.9	15	16.5	0.4
44	13	15-Jun-01	45°47.37'	58°29.45'	2.3	1.12	17.7	5.9	108	3.5	2	2.0	0.0
45	13	15-Jun-01	45°47.26'	58°21.88'	2.4	1.21	17.1	5.7	123	4.1	0	0.0	0.0
46	13	15-Jun-01	45°37.21'	58°15.41'	2.4	1.12	16.9	6.1	199	3.3	130	149.7	3.7
47	13	15-Jun-01	45°37.22'	58°25.13'	2.6	1.18	16.0	6.5	113	3.5	15	17.7	0.4
48	13	15-Jun-01	45°33.11'	58°23.40'	2.5	1.19	16.9	6.4	118	3.2	14	15.2	0.4
49	14	15-Jun-01	44°56.10'	58°19.80'	2.5	1.18	17.4	6.1	137	1.9	711	755.5	18.8
50	14	15-Jun-01	44°50.53'	58°31.40'	2.5	1.15	17.0	6.6	135	1.6	248	276.6	6.9
51	14	15-Jun-01	44°48.38'	58°36.69'	2.6	1.27	16.9	6.1	137	1.6	83	84.7	2.1
52	14	16-Jun-01	44°55.78'	58°43.20'	2.6	1.26	17.5	6.0	143	1.4	287	283.2	7.0
53	14	16-Jun-01	44°47.85'	58°52.99'	2.5	1.22	17.3	5.8	145	1.6	187	192.1	4.8
54	14	16-Jun-01	44°39.63'	59°00.79'	2.7	1.26	15.8	6.1	114	1.3	362	395.1	9.8
55	14	16-Jun-01	44°48.20'	59°04.80'	2.6	1.23	16.1	5.9	116	1.3	82	89.8	2.2
56	14	16-Jun-01	44°47.80'	59°10.96'	2.5	1.26	16.7	6.1	129	1.3	419	432.1	10.7
57	14	16-Jun-01	44°51.14'	59°25.89'	2.6	1.24	16.6	6.1	134	1.7	676	714.9	17.7
58	14	16-Jun-01	44°41.32'	59°34.23'	2.6	1.26	16.7	6.1	117	1.9	957	991.2	24.6
59	14	16-Jun-01	44°41.17'	59°45.01'	2.5	1.24	16.1	6.1	115	2.0	64	70.2	1.7
60	14	16-Jun-01	44°50.00	59°48.65	2.5	1.23	17.4	6.1	125	2.0	161	162.8	4.0
61	15	18-Jun-01	45°01.31	60°56.00	2.6	1.23	17.4	6.2	110	1.7	39	39.5	1.0
62	15	18-Jun-01	44°56.99	61°03.39	2.3	1.12	17.3	6.2	106	1.6	10	11.2	0.3
63	15	18-Jun-01	44°53.54	60°58.85	2.3	1.12	17.4	5.9	135	1.6	124	138.5	3.4
64	15	18-Jun-01	44°50.38	60°55.20	2.3	1.12	16.6	5.7	130	1.6	122	142.5	3.5
65	15	18-Jun-01	44°45.37	60°51.94	2.3	1.03	16.9	6.1	146	1.6	1329	1661.5	41.2
66	15	18-Jun-01	44°53.80	60°45.93	2.3	1.19	16.5	5.9	104	1.5	79	87.6	2.2
67	15	19-Jun-01	44°59.07	60°45.30	2.3	1.13	16.9	6.1	106	1.5	26	29.5	0.7
68	15	19-Jun-01	44°51.05	60°45.19	2.3	1.17	16.9	6.1	150	1.6	117	128.3	3.2
69	15	19-Jun-01	44°51.56	60°38.84	2.0	1.16	17.2	6.1	146	1.5	59	64.7	1.6
70	15	19-Jun-01	44°53.70	6025.37	2.3	1.16	16.9	6.1	133	2	253	281.1	7.0
71	15	19-Jun-01	44°58.79	60°14.10	2.3	1.07	16.3	6.0	107	1.6	248	309.2	7.7
72	15	19-Jun-01	44°50.96	60°16.82	2.3	1.08	16.8	6.2	136	1.7	302	362.4	9.0
73	15	19-Jun-01	44°46.72	60°16.99	2.4	1.18	17.1	6.3	180	1.8	101	109.2	2.7
74	15	19-Jun-01	44°40.62	60°19.46	2.3	1.09	16.8	5.6	125	1.7	119	141.5	3.5
75	15	19-Jun-01	44°42.07	60°13.39	2.3	1.14	17.0	6.2	123	2.2	80	89.7	2.2
Average					**2.4**	**1.1**	**16.9**	**6.1**	**120.2**	**2.2**	**159.7**	**181.2**	**4.5**

Table 5. Questionnaire results, including number of respondents, and average response values for questions on catch rates (cpue), overall abundance, effort required to catch the quota, amount of area fished , depth fished, difficulty in "making the count" and the appropriateness of the current TAC. Responses were given on a 5 point scale in which 1 was much less, 3 was no change and 5 was much more relative to the previous year.

	n	cpue	abund.	effort	area	depth	count	TAC
1994	17	4	4.6	3.1	3.4			2.6
1995	20	3.6	3.7	3	2.8			2.8
2000	13	3.9	3.6	2.3	2.3	2.7	2.8	3.1
2001	7	3.4	3.2	2.9	2.9	2.7	2.7	3.2

Table 6. Minimum survey population numbers at age with proportions at each age from the population at length estimates determined with MIX. Numbers x 10-7.

	95	96	97	98	99	00	01	Ave.
2	359	307	129	40	166	280	230	216
3	1,046	276	1,159	785	27	757	422	639
4	876	1,248	1,257	1,884	3,010	0	820	1,299
5+	1,702	2,162	1,539	2,047	1,952	3,374	2,483	2,180
	3,983	3,993	4,084	4,755	5,155	4,412	3,954	4,334

Table 7. Survey biomasses, commercial shrimp catches and exploitation rates (catch/biomass) by SFA (13-15, offshore part), and the inshore area (17), 1995-2001.

		1995	1996	1997	1998	1999	2000	2001
BIOMASS(mt)	13	4837	6838	5920	7187	9517	5919	4089
	14	9067	12094	9471	11278	11039	9544	12325
	15	5299	6610	4736	4548	7806	7213	2073
	17	4415	3663	6220	9530	8262	9183	6541
	total	**23620**	**29206**	**26349**	**32545**	**36625**	**31860**	**25038**
CATCH(mt)	13	168	55	570	514	612	301	588
	14	2265	2299	2422	2012	1503	2009	1616
	15	715	817	583	618	589	1609	1132
	17	0	0	0	787	2121	1498	1629
	total	**3148**	**3171**	**3575**	**3930**	**4825**	**5417**	**4965**
EXPLOITATION(%)	13	3.5	0.8	9.6	7.1	6.4	5.1	14.4
	14	25.0	19.0	25.6	17.8	13.6	21.0	13.1
	15	13.5	12.4	12.3	13.6	7.5	22.3	54.6
	17	0.0	0.0	0.0	8.3	25.7	16.3	24.9
	total	**13.3**	**10.9**	**13.6**	**12.1**	**13.2**	**17.0**	**19.8**

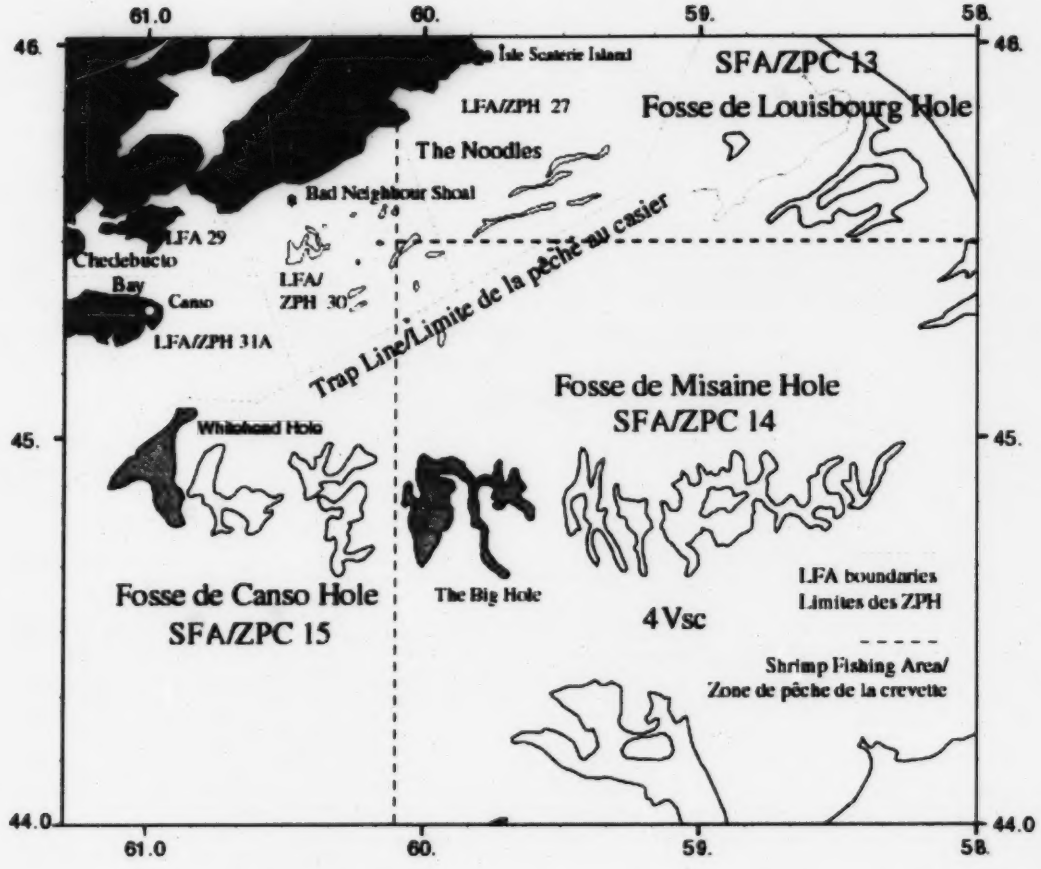

Figure 1. Shrimp Fishing Areas (SFAs) on the Eastern Scotian Shelf. The lobster Fishing Areas (LFAs) used to allocate shrimp trap licences, and the shrimp trap line are also shown. Trappers are prohibited from fishing seaward of this line. Another line (not shown) prohibits trawlers from fishing inside Chedebucto Bay during the trapping season (fall to spring).

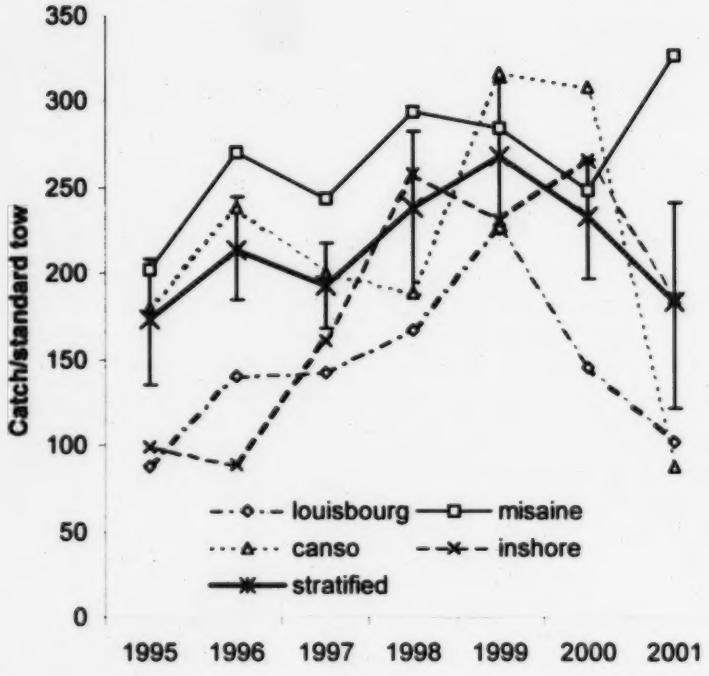

Figure 2. Stratified catch/standard tow for DFO-industry co-operative surveys 1995-2001 and unstratified estimates for the individual shrimp holes. Louisbourg Hole is mainly SFA 13, Misaine is SFA 14, and Canso is the offshore part of SFA 15. The Inshore, or Area 17, is comprised of inshore parts of SFA 13-15.

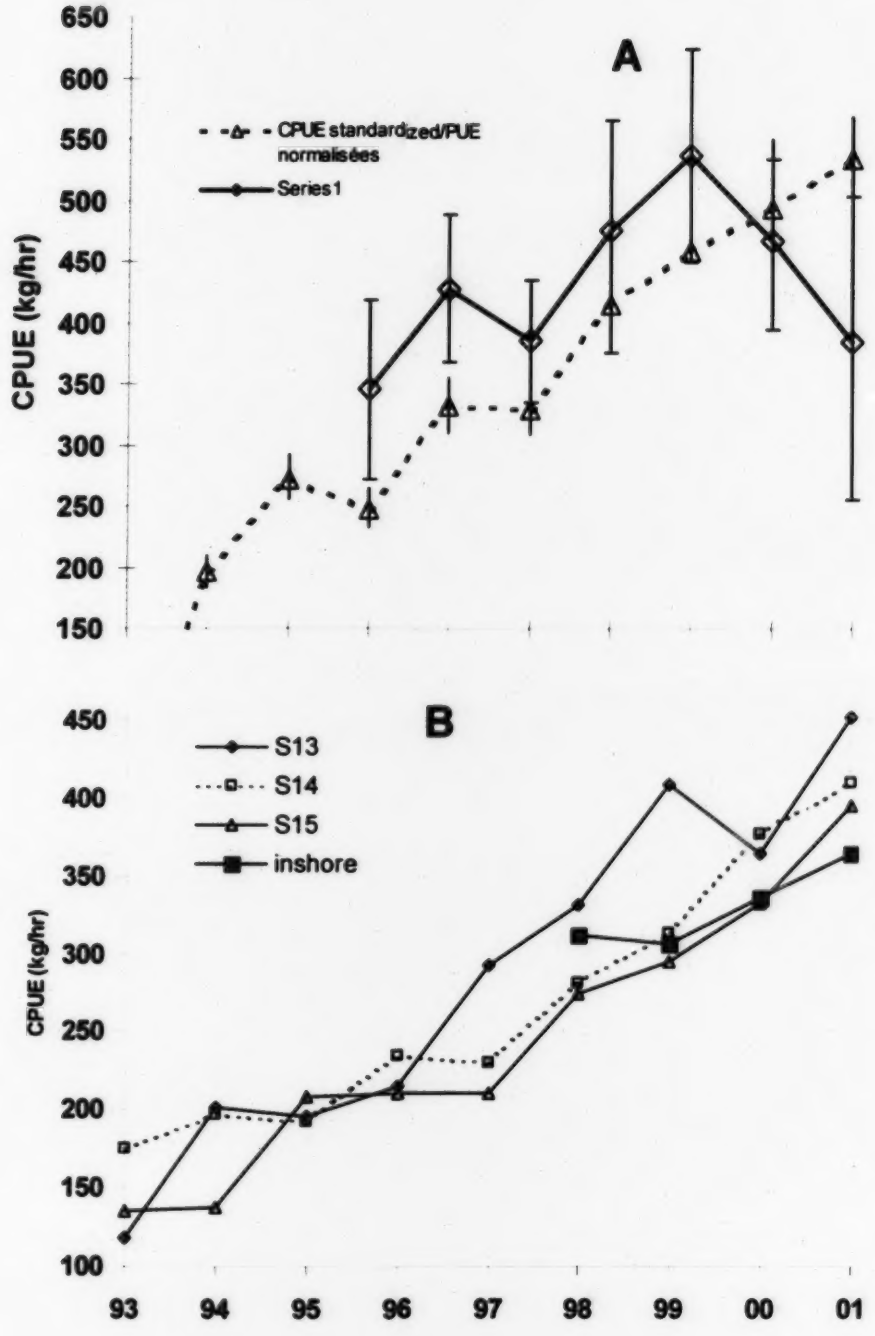

Figure 3. A - Survey stratified estimate and standardised CPUE with 95% confidence intervals, and B - unstandardised commercial CPUE for each fishing area. Note that SFA15 includes the inshore, but the latter is also shown separately since fishing began there in 1998.

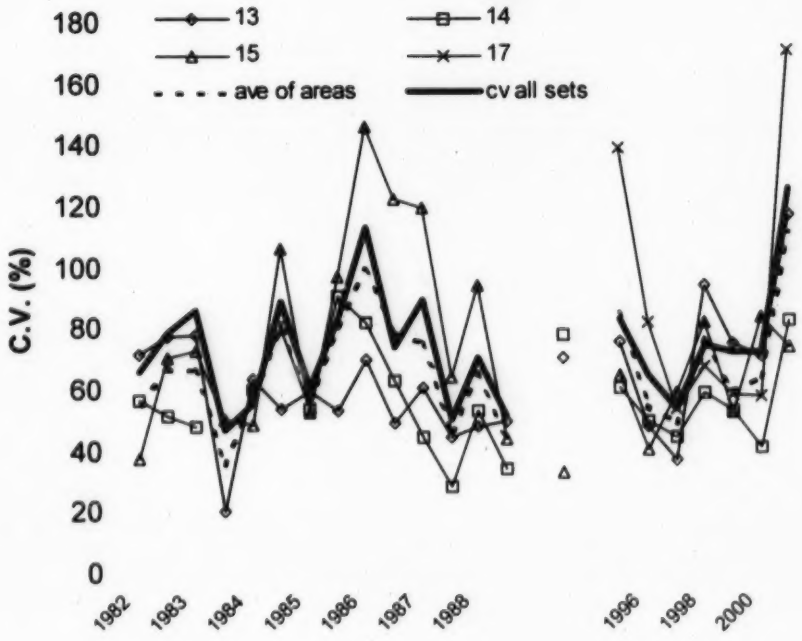

Figure 4. Coefficients of variation (C.V.) for individual shrimp fishing areas from shrimp surveys. Note that the earlier survey series has two values per year, one for the spring and one for the fall survey.

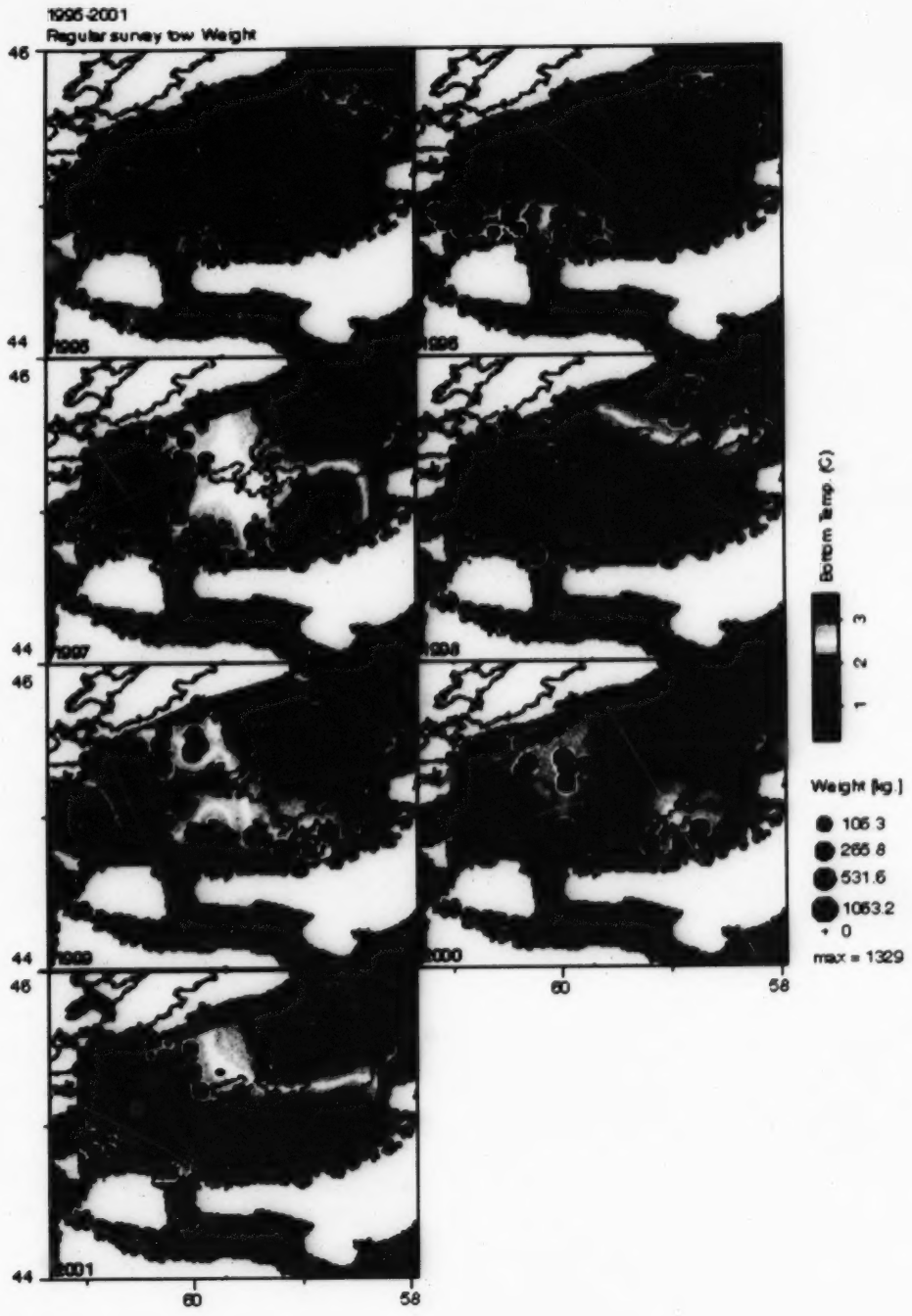

Figure 5. Distribution of catches and bottom temperatures from DFO-industry surveys 1995-01.

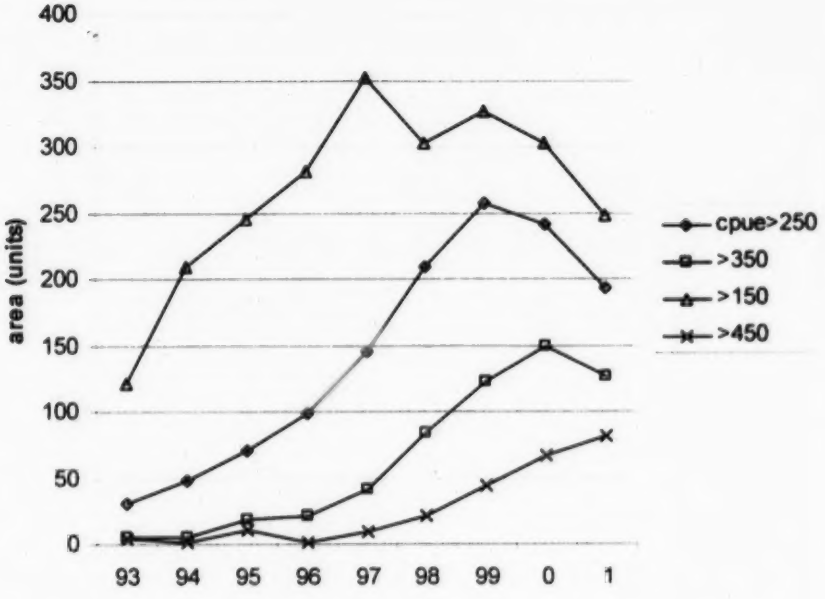

Figure 6. Number of 1 minute square unit areas fished by the shrimp fleet with mean catch rates above the values specified in the legend.

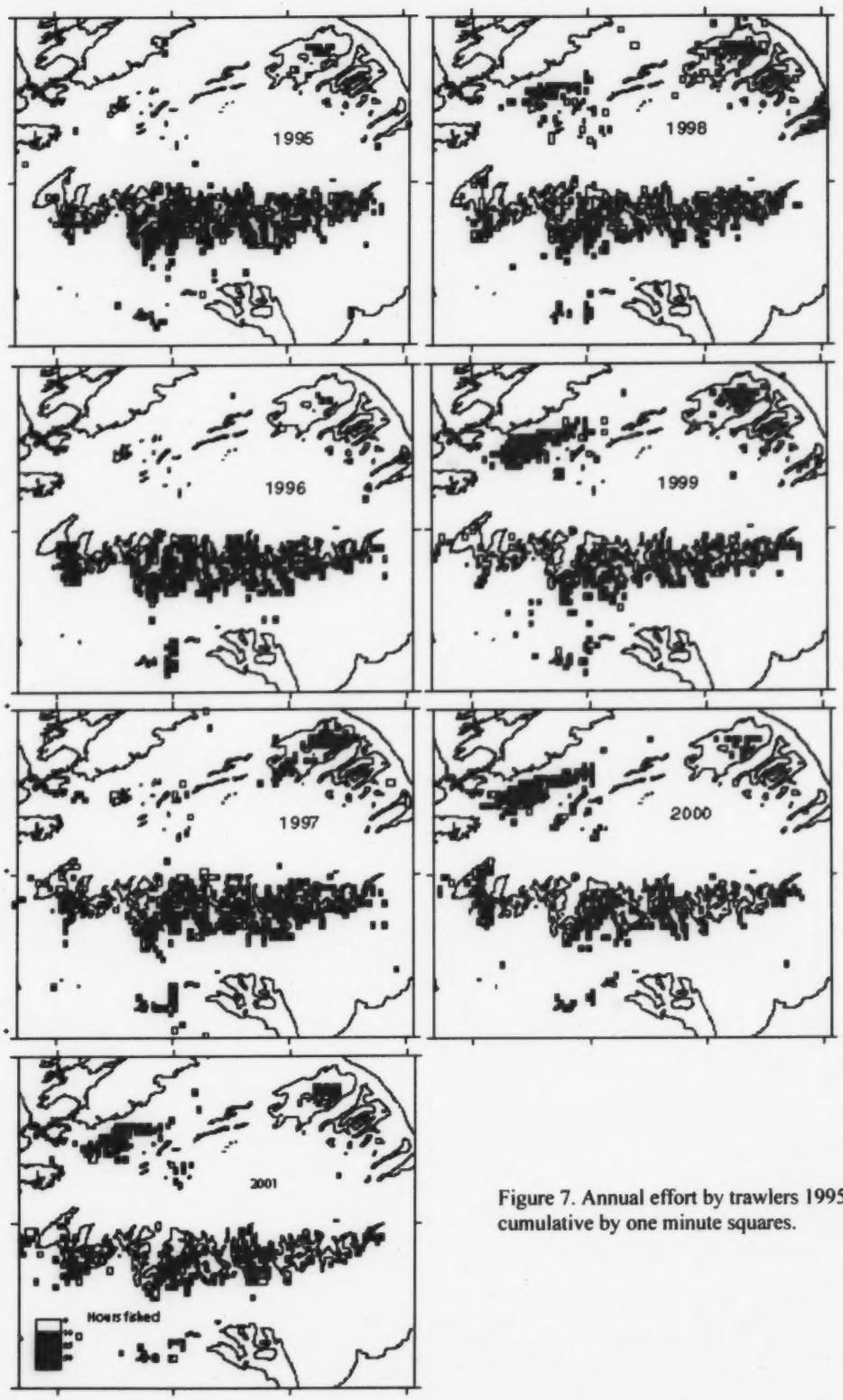

Figure 7. Annual effort by trawlers 1995-2001, cumulative by one minute squares.

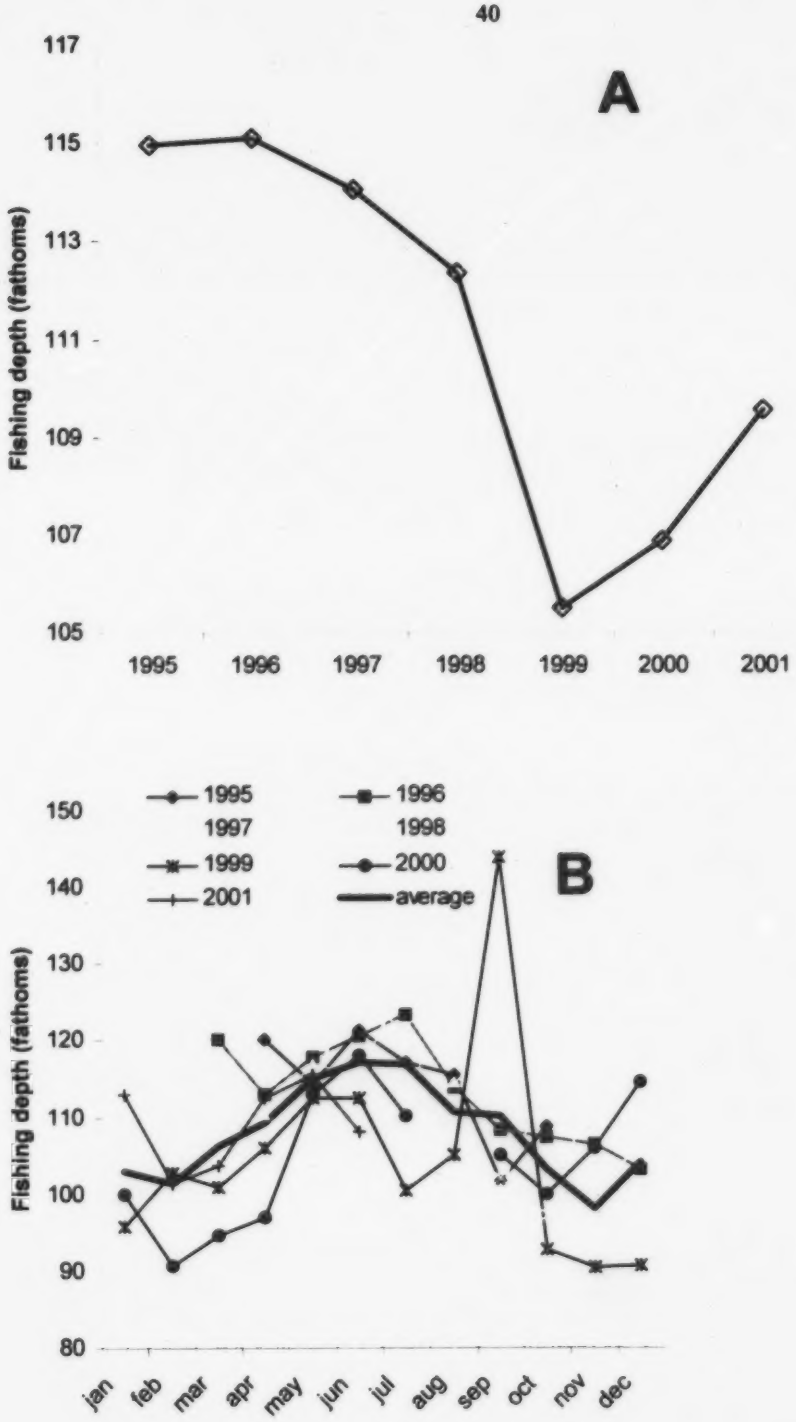

Figure 8. A. Annual mean fishing depth by commercial trawlers, and B. Monthly mean fishing depth for commercial trawlers 1995-2001

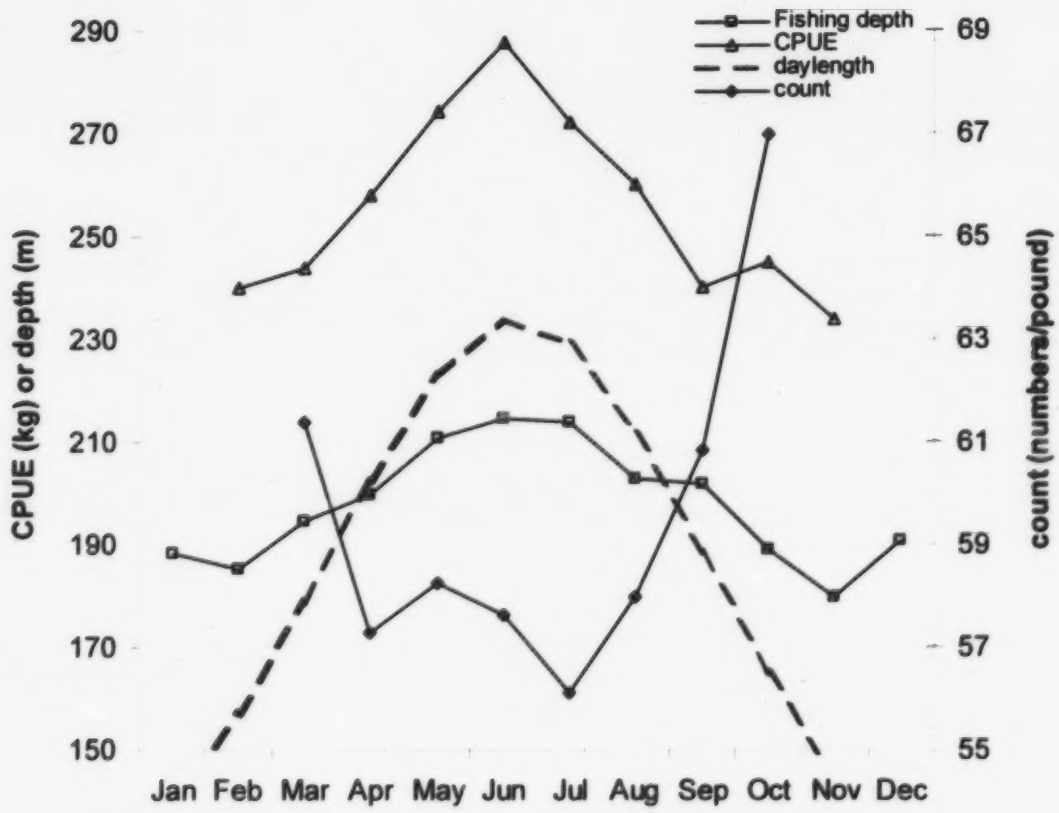

Figure 9. Monthly average commercial CPUE, fishing depth, counts/pound and relative day length for the offshore fishing holes (SFA 13, 14 and 15).

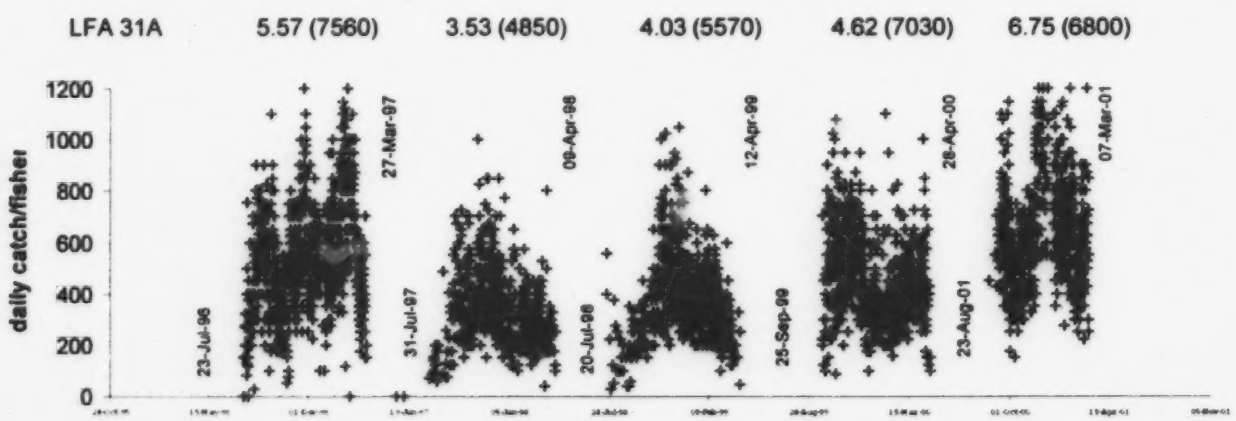

Figure 10. Mean daily catches per trap haul for the Canso trap fishery. The dates indicate the beginning and end of the fishery each year (there is no season restriction) and the values at the top indicate annual mean catches per trap haul and total effort (trap hauls).

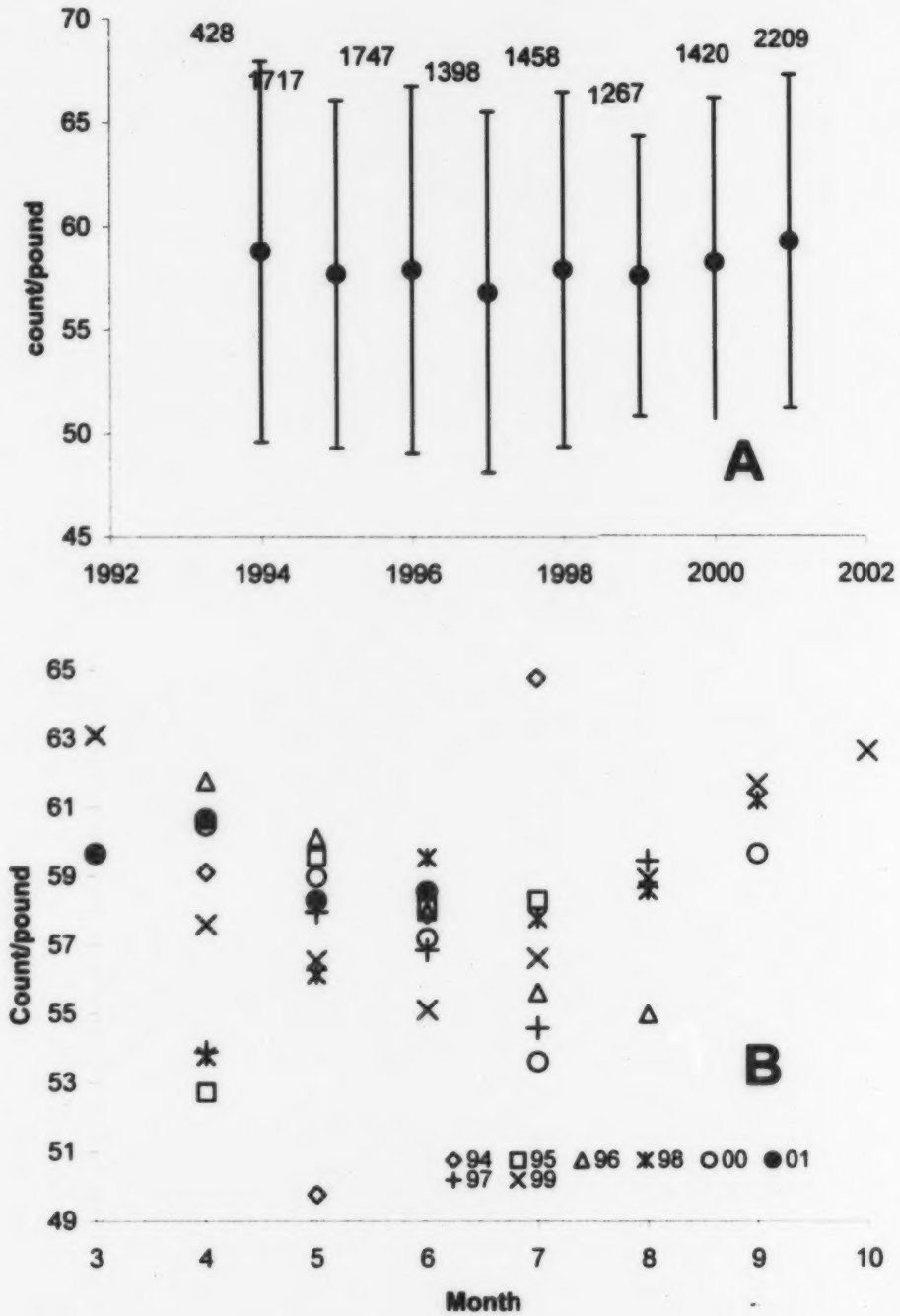

Figure 11. Annual (A) and monthly (B) mean commercial shrimp counts per pound for vessels landing in Canso. The bars in the upper figure represent 1 standard deviation and the numbers above each bar are the number of observations.

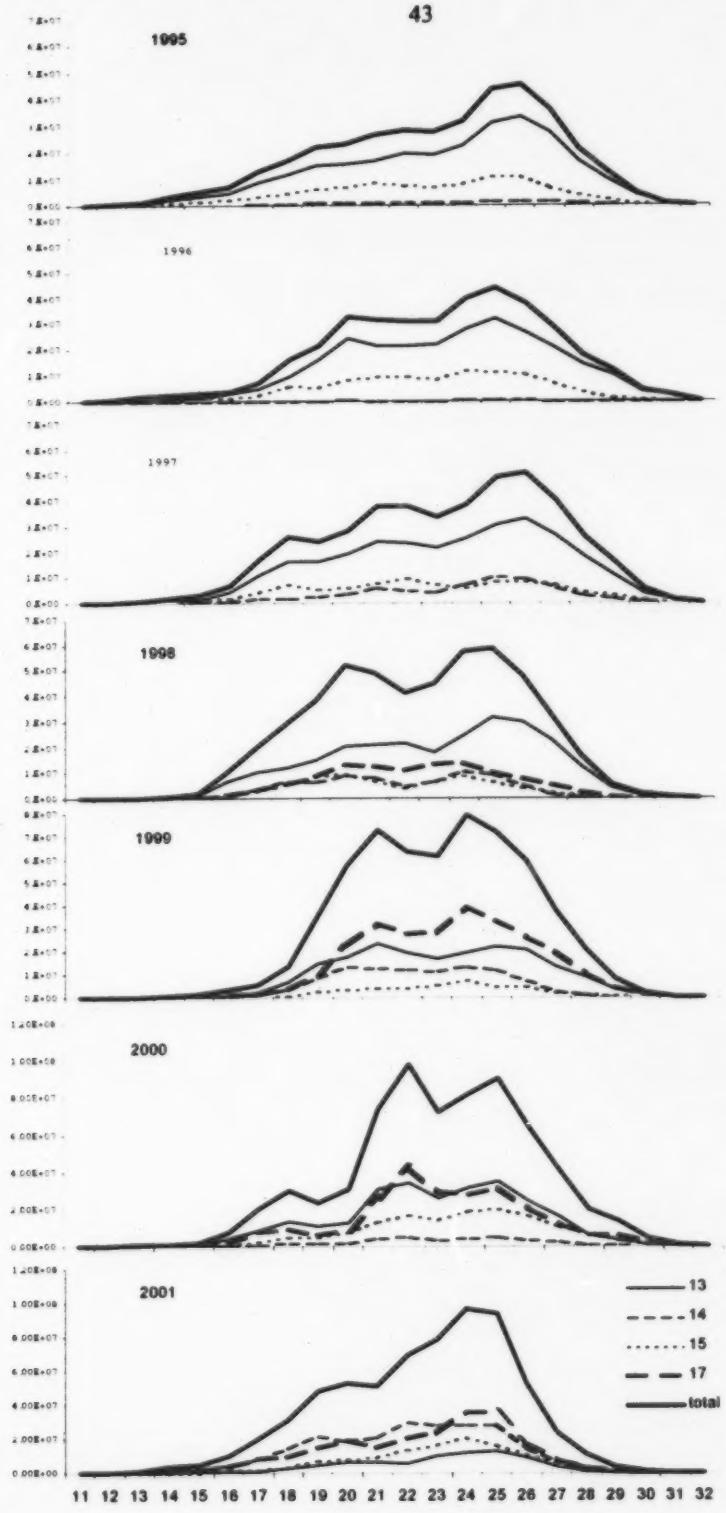

Figure 12. Catch at length from commercial sampling, 1995-2001

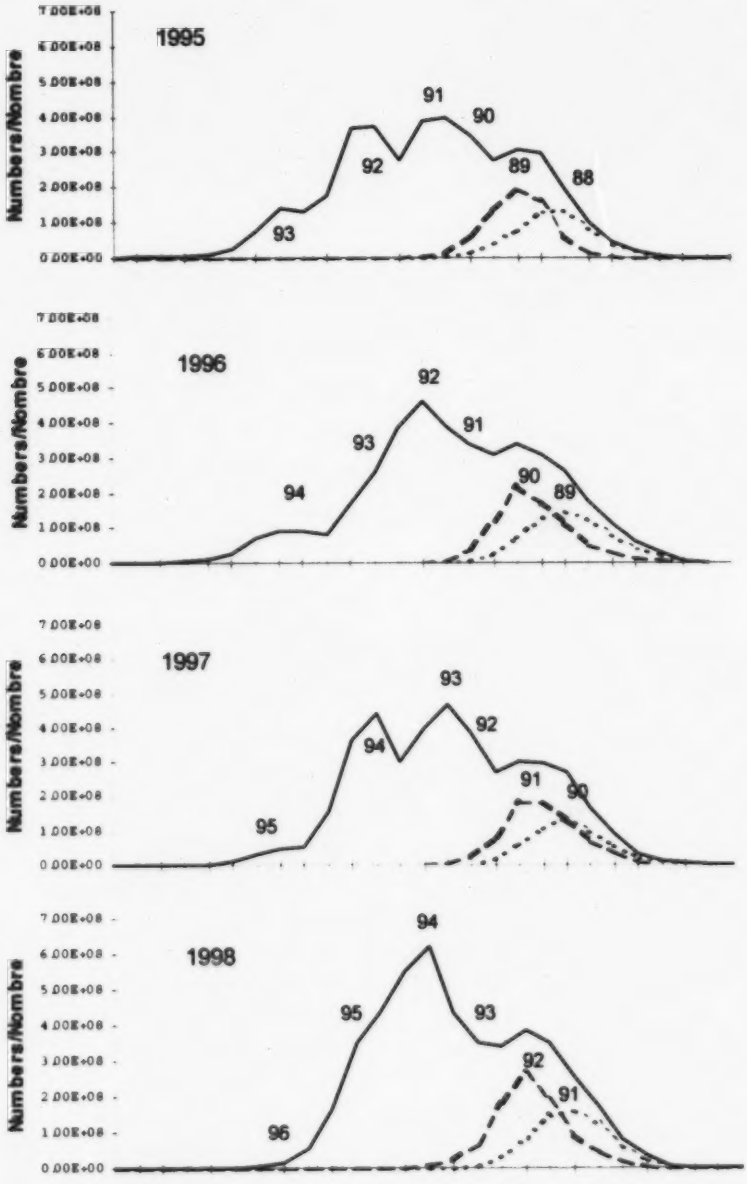

Figure 13. Population estimates at length from DFO-industry surveys. The heavy dotted line in each figure represents transitional and primiparous shrimp, and the stippled line represents multiparous shrimp.

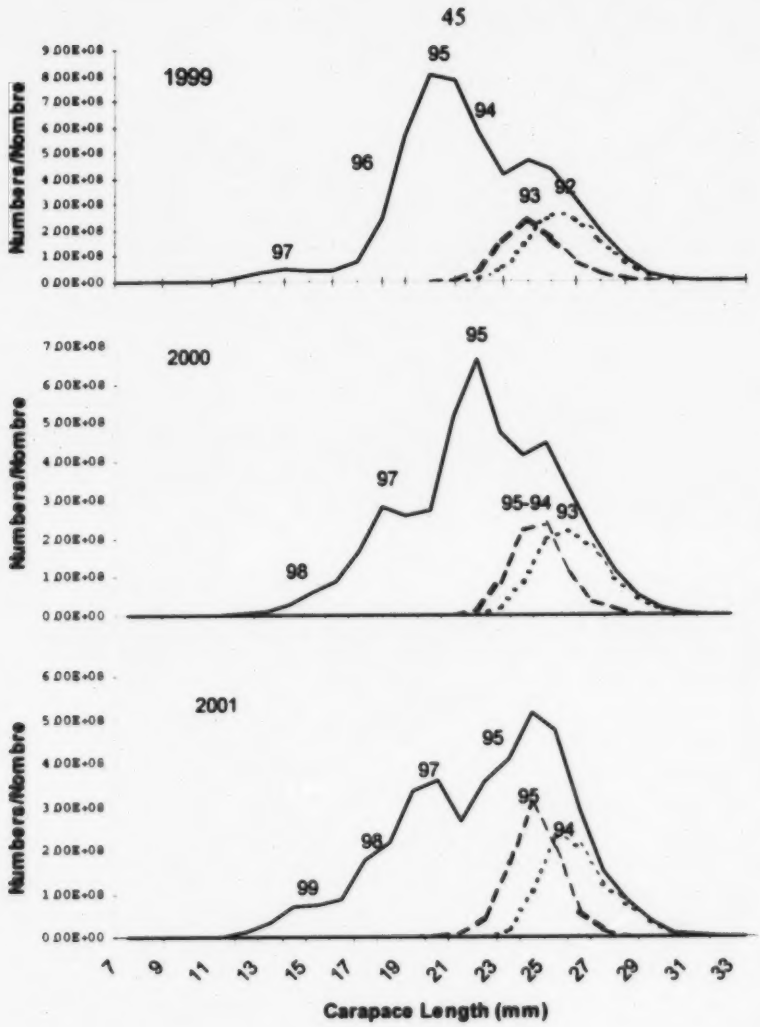

Figure 13. Continued.

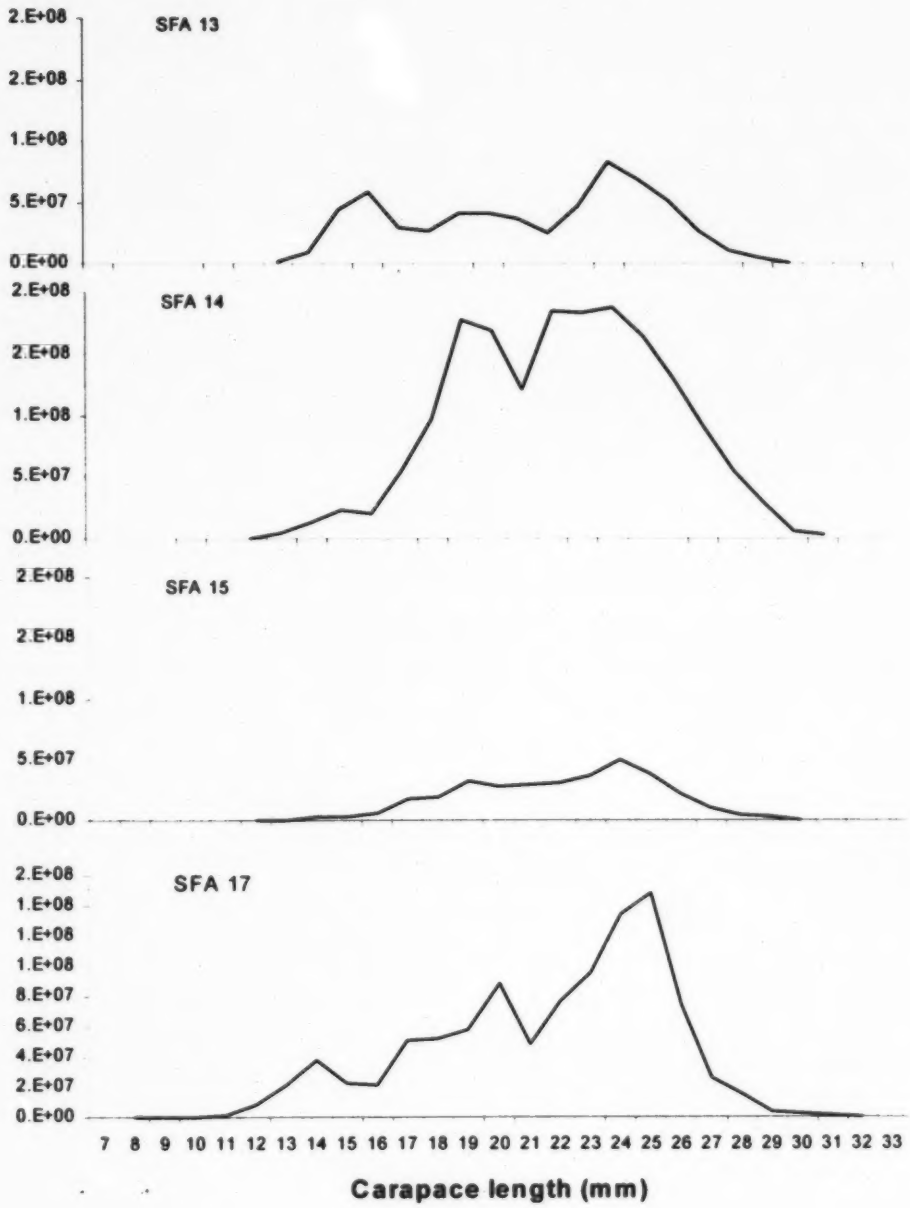

Figure 14. Population at length estimates by Shrimp Fishing Area from the DFO-Industry survey conducted in June, 2001.

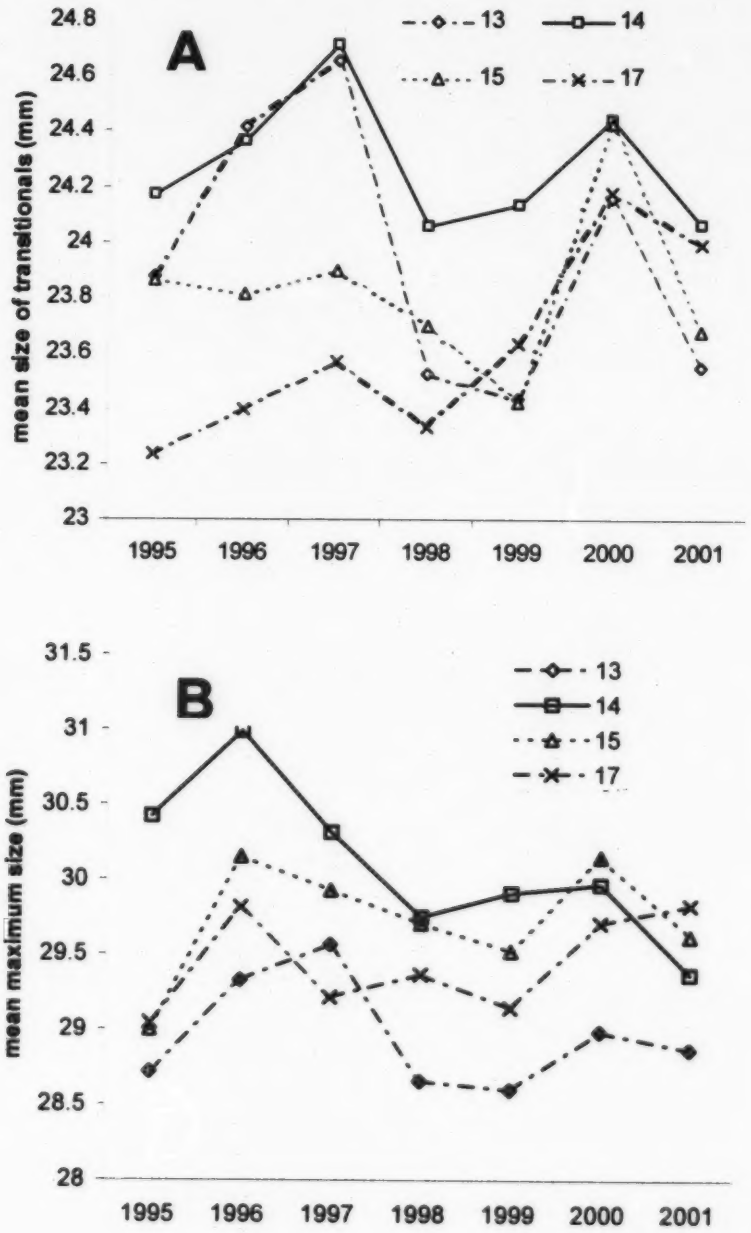

Figure 15. Average size at A. sex transition and B. maximum size by shrimp fishing area for the DFO-industry surveys 1995-2001.

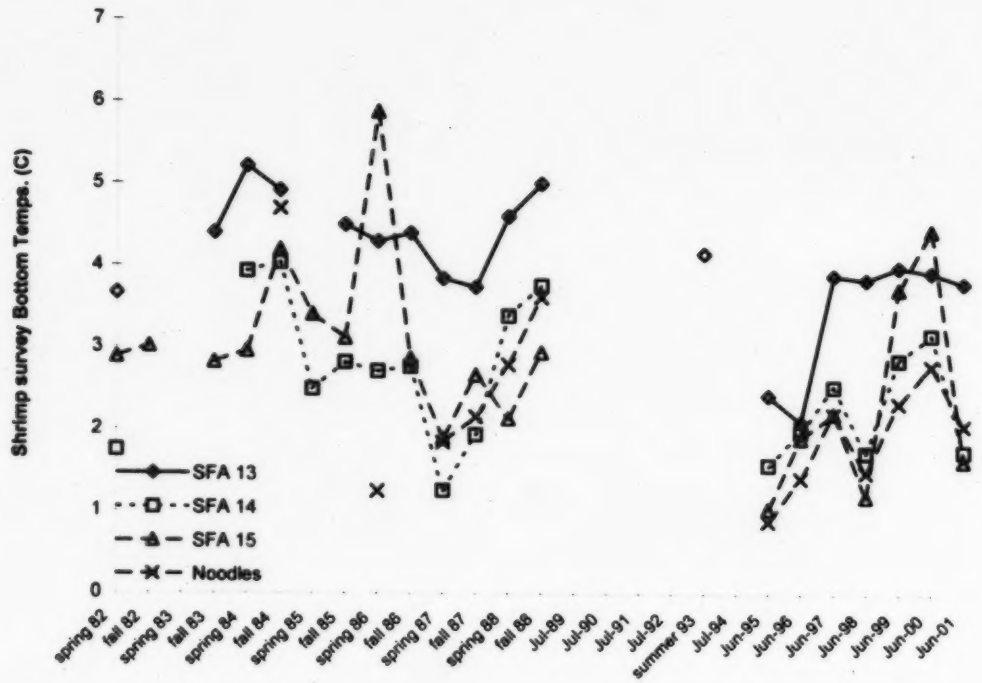

Figure 16. Mean bottom temperatures from shrimp surveys by SFA. Note that both spring and fall values were available from the earlier series (1982-88), but only one survey (June) was conducted annually in the recent series.

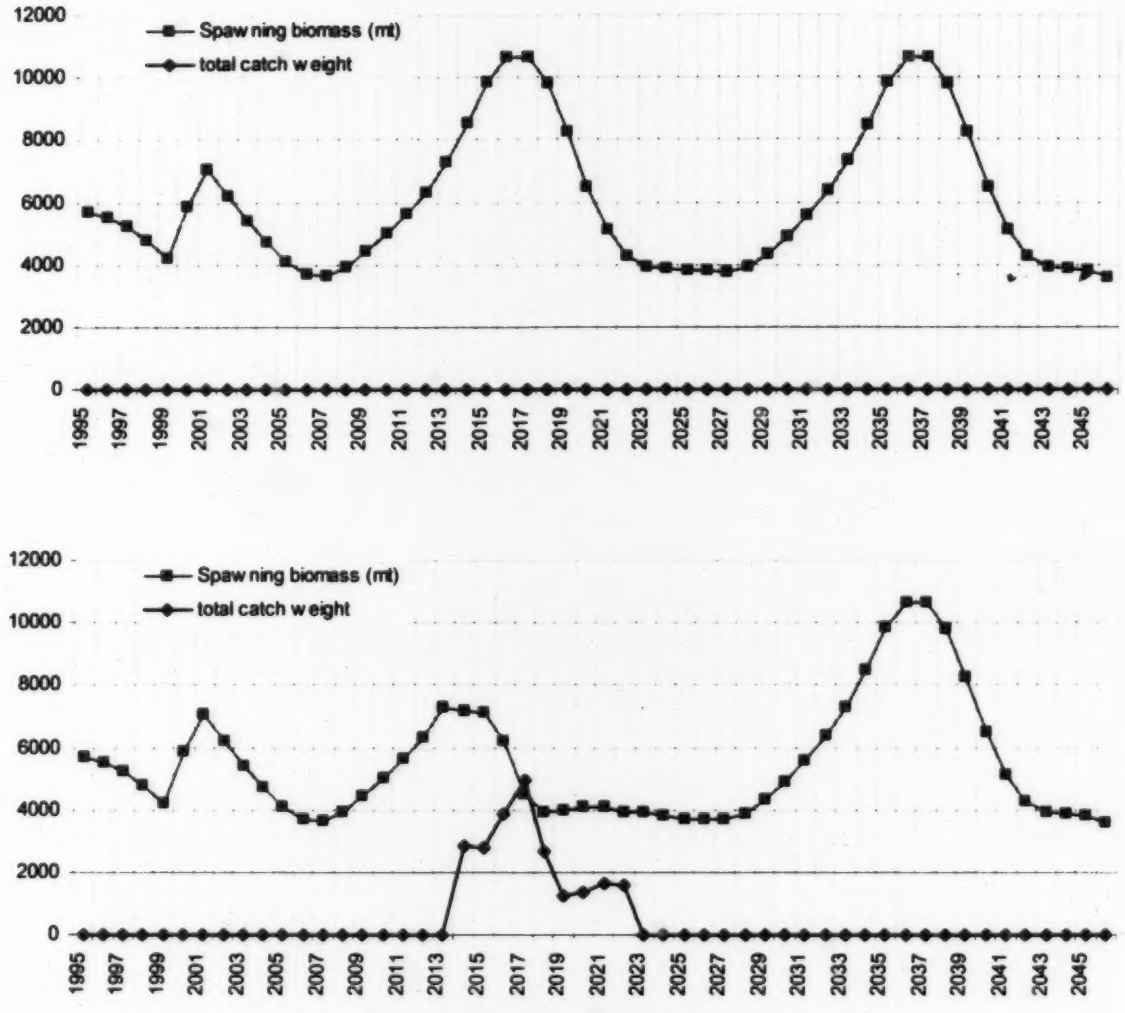

Figure 17. Simulation results including no fishing (top), and fishing (bottom) with TAC increases similar to those experienced on the Scotian Shelf, and decreases during the period of environmentally induced decline to keep the spawning stock biomass at or above the lowest level observed.

Appendix 1.

Questionnaire on the 2001 Scotian Shelf Shrimp fishery

Background

Name of Captain: _____

Shrimp license number: _____

CFV number: _____

Percentage of the above vessel's shrimp trips in 2001 for which you were aboard: _____

Total number of years you have fished shrimp: _____

Non-shrimp fishing experience: _____ _____

Shrimp Gear:

What type/make of shrimp trawl was used on this vessel in 2001?: _____

Who is the manufacturer?: _____

What type/make of doors were used?: _____

What type of codend did you use in 2001? square____ % of trips: diamond____ % of trips

What type of grate do you use (spacing, material, 2nd grate, floats): _____

_____

Describe any significant changes to your gear in the last few years that may have affected your fishing _____

_____

Please circle the appropriate number in answer to the following questions

Stock status in shrimp fishing areas 13, 14 and 15

My shrimp catch per haul (per hour fished) in 2001 was:
1 - much lower, 3 - about the same, 5 - much higher than in 2000. 1 2 3 4 5

In 2001 there was: 1 - Much less shrimp, 3 - about the same amount of shrimp, 5 - much more shrimp than in 2000. 1 2 3 4 5

Fishing Effort

In 2001, to catch my quota I had to fish :
1 – not as hard, 3 - about the same, 5 - much harder than in 2000. 1 2 3 4 5

In 2001 I fished in:

1 - a much smaller area, 3 - about the same area, 5 - a much larger area than 2000. 1 2 3 4 5

In 2001 I fished:
1 - shallower, 3 - about the same area, 5 - deeper than 2000. 1 2 3 4 5

Making the count in 2001 was:
1 – much easier, 3 - about the same area, 5 – much harder than in 2000. 1 2 3 4 5

Describe any change in circumstances e.g. price structure of shrimp, catch rates, gear problems/changes, gear conflicts, etc. that changed the way you fished in 2001._____

_____

_____

_____

Biology

Have you noticed any differences in the shrimp recently (eggs, softness, size, distribution, etc.)?

_____

Have you noticed any difference in the bycatch amounts or composition? e.g. capelin, turbot

_____

Do you have any questions about the biology of shrimp?

_____

Management of the fishery

The current size of the shrimp Total Allowable Catch is:
1 - much too low, 3 - about the right size, 5 - much too high. 1 2 3 4 5

Describe any changes to the management of shrimp stock that you would like to see discussed and/ or implimented (e.g. new management measures that should be considered to protect the resource)_____

_____

_____

_____

additional comments on any subject:

_____